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RESEARCH MEMORANDUM

THE EFFECT OF RAKING THE AILERON TIPS ON THE LATERAL-CONTROL AND HINGE-MOMENT CHARACTERISTICS OF A 20-PERCENT-CHORD PARTIAL-SPAN OUTBOARD AILERON ON A WING WITH LEADING EDGE SWEPT BACK 51.3°

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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THE EFFECT OF RAKING THE AILERON TIPS ON THE LATERAL-CONTROL AND HINGE-MOMENT CHARACTERISTICS OF A 20-PERCENT-CHORD PARTIAL-SPAN OUTBOARD AILERON ON A WING WITH LEADING EDGE SWEPT BACK 51.3°

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SUMMARY

A wind-tunnel investigation was made at low speed to determine the lateral-control and hinge-moment characteristics of a 20-percent-chord unsealed partial-span outboard aileron having various plan forms on a semispan-wing model with aspect ratio of 3.06, taper ratio 0.49, and 51.3° sweepback of the wing leading edge. The various aileron plan forms were obtained by raking the aileron tips from 20° in the outboard direction to 80° in the inboard direction.

These changes in aileron plan form had an appreciable effect on the aileron hinge-moment parameter C_{h_δ}, the aileron with tips parallel to the plane of symmetry having lower values of C_{h_δ} than the aileron with tips normal to the hinge line. These changes in aileron plan form had only slight effects on the variation of rolling-moment coefficient with aileron deflection C_{l_δ} for ailerons having the same area.

INTRODUCTION

An investigation of a 51.3° sweptback wing equipped with 16.7-percent-chord plain flaps and ailerons having various spans was made in the Langley 300 MPH 7- by 10-foot tunnel and the results are presented in reference 1. At that time, the plan form of a 40.4-percent-semispan outboard aileron was modified so that the inboard tip of the aileron was parallel to the plane of symmetry instead of perpendicular to the hinge line. This change in aileron plan form resulted in a large reduction in the slope of the curves of hinge-moment coefficient against small aileron deflection and a relatively small reduction in aileron effectiveness.

The present paper contains the results of a more extensive investigation, made in the Langley 300 MPH 7- by 10-foot tunnel, of the effect of similar variations in aileron plan form on hinge moment and control effectiveness. The data presented and discussed herein were obtained on a 20-percent-chord, partial-span, outboard, plain-radius-nose, unsealed, flat-sided aileron on a wing having a leading-edge sweepback of 51.3°, aspect ratio 3.06, taper ratio 0.49, and NACA 65_1-012 airfoil perpendicular to the 55.6-percent-chord line. The change of aileron plan form was accomplished by raking the aileron tips through a range of angles which extended from 20° outboard (20°) to 80° inboard (-80°).

Characteristics of the wing in pitch were determined through a large angle-of-attack range for the neutral aileron condition. Rolling-moment, yawing-moment and hinge-moment characteristics were determined for all the aileron plan forms investigated.

DEFINITIONS AND SYMBOLS

The forces and moments on the wing are presented about the wind axes which, for the conditions of these tests (zero yaw), correspond to the stability axes. (See fig. 1.) The axes intersect at the plane of symmetry and the chord plane of the model at 27.8 percent mean aerodynamic chord as shown in figure 2.

The rolling-moment and yawing-moment coefficients determined on the semispan wing represent the aerodynamic effects that occur on a complete wing as the result of deflection of one aileron. The lift, drag, and pitching-moment coefficients determined on the semispan wing (with the aileron neutral) represent those that occur on a complete wing.

The symbols used in the presentation of results are as follows:

C_L lift coefficient $\left(\frac{\text{Twice lift of semispan model}}{qS}\right)$

C_D drag coefficient $\left(\frac{\text{Twice drag of semispan model}}{qS}\right)$

C_m pitching-moment coefficient referred to $0.278\bar{c}$ $\left(\frac{\text{Twice pitching moment of semispan model}}{qS\bar{c}}\right)$

C_l rolling-moment coefficient $\left(\frac{L}{qSb}\right)$

C_n yawing-moment coefficient $\left(\frac{N}{qSb}\right)$

C_h aileron hinge-moment coefficient

$$\left(\frac{H}{2q(\text{area moment of aileron rearward of and about aileron hinge axis})}\right)$$

b twice span of semispan model, 6.066 feet

A aspect ratio of wing, 3.06 $\left(b^2/S\right)$

S twice area of semispan model, 12.06 square feet

L rolling moment due to aileron deflection, foot-pounds

N yawing moment due to aileron deflection, foot-pounds

H aileron hinge moment, foot-pounds

q free-stream dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$

V free-stream velocity, feet per second

ρ mass density of air, slugs per cubic foot

y lateral distance from plane of symmetry, feet

c local wing chord measured in planes parallel to wing plane of symmetry

c' local wing chord measured in planes perpendicular to wing 0.556c line

$\bar{c}$ wing mean aerodynamic chord, 2.087 feet $\left(\frac{2}{S}\int_0^{b/2} c^2 dy\right)$

c_a local aileron chord measured along wing-chord plane from hinge axis of aileron to trailing edge of aileron in planes parallel to wing plane of symmetry

c_a' local aileron chord measured along wing-chord plane from hinge axis of aileron to trailing edge of aileron in planes perpendicular to 0.556c line

α angle of attack with respect to chord plane at root of model, degrees

δ aileron deflection, corrected for deflection under load, relative to wing-chord plane and measured in plane perpendicular to aileron hinge axis, degrees

$$C_{h_\alpha} = \left(\frac{\partial c_h}{\partial \alpha}\right)_\delta$$

$$C_{h_\delta} = \left(\frac{\partial c_h}{\partial \delta}\right)_\alpha$$

$$C_{l_\delta} = \left(\frac{\partial c_l}{\partial \delta}\right)_\alpha$$

The subscripts δ and α outside the parentheses indicate that the factor was held constant. All slopes were measured in the vicinity of 0° angle of attack and 0° aileron deflection.

CORRECTIONS

All the test data have been corrected for jet-boundary and reflection-plane effects by the method of reference 2. Blockage corrections as determined from reference 3, to account for the constriction effects produced by the wing model and wing wake, were also applied. Aileron deflections have been corrected for deflection under load, but the rolling-moment-coefficient data have not been corrected for the small amount of wing twist produced by the aileron deflection.

APPARATUS AND MODEL

The semispan sweptback-wing model was mounted vertically in the Langley 300 MPH 7- by 10-foot tunnel, as shown in figure 3, with the ceiling serving as a reflection plane. The model was mounted on the balance system in such a manner that all forces and moments acting on the model could be measured. A small clearance gap was maintained between the model and the tunnel ceiling and a small end plate was attached to the root of the model to deflect the spanwise flow of air that enters the tunnel test section through the opening. The aileron hinge moments were measured with an electric resistance-type strain gage.

The model used for these tests was built of aluminum to the plan-form dimensions shown in figure 2. The model had an aspect ratio of 3.06, a taper ratio of 0.49, and a leading-edge sweepback of 51.3°. The wing sections perpendicular to the 55.6-percent-chord line were of NACA 65_1-012 airfoil profile.

The model was equipped with a 20-percent-chord flat-sided unsealed aileron which had a plain radius nose. The aileron span with aileron tips parallel to the plane of symmetry was 39 percent of the wing semi-span, and the outboard aileron tip was located 6.8 percent of the wing semispan inboard of the wing tip. The wing and aileron were equipped with removable blocks such that either or both the tips of the aileron could be raked as shown in figure 2. Angles obtainable between ends of the aileron and the plane of symmetry were 20°, 0°, -20°, -41.7° (tip of aileron perpendicular to hinge line), and -80°. A positive value designates the rake angle measured from the plane of symmetry outboard toward the wing tip.

TESTS

All the tests were made at an average dynamic pressure of 148.5 pounds per square foot which corresponds to a Mach number of 0.328 and a Reynolds number of 4,450,000 based on the wing mean aerodynamic chord of 2.087 feet.

Wing-angle-of-attack and lateral-control tests with the aileron deflected various amounts from 0° to -30° were made through an angle-of-attack range from -28° to 28° for the various aileron plan forms investigated.

RESULTS AND DISCUSSION

Wing Aerodynamic Characteristics

The aerodynamic characteristics in pitch of the wing, equipped with a flat-sided aileron, are presented in figure 4. The same data through a Mach number range from 0.302 to 0.913 are presented in reference 4 for the subject wing equipped with a true contour (cusped trailing edge) aileron. The aerodynamic characteristics (fig. 4) are in good agreement with the aerodynamic characteristics at low Mach numbers presented and discussed in reference 4. For this reason the aerodynamic characteristics in pitch are not discussed in the present paper.

Lateral-Control and Hinge-Moment Characteristics

The variation of the lateral-control and hinge-moment characteristics with aileron deflection and wing angle of attack for each of the aileron plan forms are presented in figures 5 to 9. The lateral-control parameters C_{l_δ}, C_{h_δ}, and C_{h_α} determined from the data in figures 5 to 9 are shown plotted against the angle of the variable tip of the aileron relative to the plane of symmetry in figure 10 and are summarized in table I.

The aileron span and spanwise locations are the same for all the aileron plan forms of this investigation as measured at the hinge line. Consideration has been given however, to the effective span and spanwise locations of the various aileron configurations in the discussion of the lateral-control characteristics. This effective span is defined as the lateral distance, in the usual spanwise direction, between the midpoint of a line along the inboard aileron tip from the hinge line to the trailing edge of the aileron to the midpoint of a similar line along the outboard aileron tip. The effective spanwise location is defined as the spanwise location of the effective aileron span.

In general, at a given aileron deflection, the variations of the rolling-moment, yawing-moment, and hinge-moment coefficients with angle of attack for the various aileron plan forms have the same trends as the aileron with tips parallel to the plane of symmetry.

Rolling-moment characteristics.- Except for the angles of attack near wing stall, the rolling-moment coefficients generally varied nearly linearly with aileron deflection up to about 20° aileron deflection and were relatively unaffected by angle-of-attack variations (figs. 5 to 9). At a given aileron deflection, as the angle of attack was increased, the rolling-moment coefficients generally decreased; this decrease was greater for large aileron deflections than for small ones.

As the inboard tip of the aileron was raked negatively (that is, the angle increased inboard from the free-stream direction) the effective span of the aileron was increased, the effective spanwise location moved inboard, and an increase in the aileron parameter C_{l_δ} resulted, as shown in figure 10. As the angle of the outboard tip of the aileron was increased in the inboard direction, the effective span of the aileron and C_{l_δ} decreased. When both tips of the aileron were kept parallel and the aileron tips were raked inboard up to -41.7°, the effective spanwise location moved inboard, there was a slight increase in the effective span of the aileron, and C_{l_δ} increased slightly (fig. 10). The largest value of C_{l_δ} occurred for the aileron which had the largest effective span investigated (inboard tip -80° and the outboard tip 20°, fig. 8); the smallest value of C_{l_δ} occurred for the aileron which had the smallest effective span (inboard tip 20° and the outboard tip -80°, fig. 9). These trends indicate that the aileron effectiveness parameter C_{l_δ} is dependent on the effective span and effective spanwise location of the control surface and that, for a given aileron area, plan form has little or no effect on C_{l_δ}. The results of an investigation in which changes in aileron span and spanwise location indicate the same trends in aileron effectiveness parameter C_{l_δ} as are shown in the present investigation when the effective span and spanwise locations were changed are presented in reference 5.

Aileron hinge-moment characteristics.- For the various aileron plan forms the values of the aileron hinge-moment coefficient C_h at a given aileron deflection (figs. 5 to 9) generally became more negative as the wing angle of attack increased. A fairly linear variation of C_h with aileron deflection for the range of $\pm 10^{\circ}$ δ was obtained for all the aileron plan forms investigated at angles of attack less than 16.6°. The variation of C_h with δ for the upgoing aileron generally decreased as the value of α increased.

The variation of aileron hinge-moment parameters C_{h_δ} and C_{h_α} with the angle of the variable tip of the aileron (fig. 10) shows that, as the inboard tip was raked inboard or as both the inboard and outboard tips were kept parallel while both tips were raked up to approximately -41.7° (at which angle the aileron tips were perpendicular to the hinge line), C_{h_δ} and C_{h_α} increased. As the outboard aileron tip was raked up to approximately -60°, C_{h_δ} decreased, and C_{h_α} decreased but only in the range of rake angles from 20° to 0°. The data in figure 10 also show that variation of the angle of the inboard tip of the aileron produced larger changes in C_{h_δ} than does the variation of the angle of the outboard aileron tip.

As mentioned previously, the plan form of the aileron of reference 1 was modified so that the inboard tip of the aileron was parallel to the plane of symmetry instead of normal to the hinge axis. Although a direct agreement of the results of the present investigation and the results of reference 1 for the same aileron-plan-form change should not be expected because of other geometric differences, it should be noted that the results do show the same trends in C_{l_δ}, C_{h_δ}, and C_{h_α}.

In summation it is indicated that, for ailerons having the same area, variation of aileron plan form has an appreciable effect on the aileron hinge-moment parameter C_{h_δ}, although plan form has little or no effect on C_{l_δ}. The ailerons with tips parallel to the plane of symmetry had lower values of C_{h_δ} than the ailerons with tips normal to the hinge axis. The configuration which gave a large value of C_{l_δ} (the inboard tip of the aileron was at an angle of approximately -60° with respect to the plane of symmetry) also gave the largest negative value of C_{h_δ}. The aileron with tips parallel and at an angle of 20° with respect to the free stream had a low value of the ratio $C_{h_\delta}/C_{l_\delta}$ and also the lowest value of C_{h_α}.

CONCLUSIONS

A wind-tunnel investigation made at low speed to determine the lateral-control and hinge-moment characteristics of a 51.3° sweptback semispan wing equipped with an unsealed partial-span outboard aileron having various plan forms indicated that:

1. In general, for ailerons having the same area, variation of aileron plan form has an appreciable effect on the aileron hinge-moment parameter C_{h_δ}, although plan form had little or no effect on the variation of rolling-moment coefficient with aileron deflection C_{l_δ}.

2. The aileron with tips parallel to the plane of symmetry had lower values of C_{h_δ} than the aileron whose tips were normal to the hinge line.

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2. Polhamus, Edward C.: Jet-Boundary-Induced-Upwash Velocities for Swept Reflection-Plane Models Mounted Vertically in 7- by 10-Foot, Closed, Rectangular Wind Tunnels. NACA TN 1752, 1948.

3. Herriot, John G.: Blockage Corrections for Three-Dimensional-Flow Closed-Throat Wind Tunnels, with Consideration of the Effect of Compressibility. NACA Rep. 995, 1950. (Formerly NACA RM A7B28.)

4. Schneiter, Leslie E., and Hagerman, John R.: Wind-Tunnel Investigation at High Subsonic Speeds of the Lateral-Control Characteristics of an Aileron and a Stepped Spoiler on a Wing with Leading Edge Swept Back 51.3°. NACA RM L9D06, 1949.

5. Lowry, John G., and Schneiter, Leslie E.: Estimation of Effectiveness of Flap-Type Controls on Sweptback Wings. NACA TN 1674, 1948.

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TABLE I.- SUMMARY OF THE LATERAL-CONTROL CHARACTERISTICS OF 20-PERCENT-CHORD

AILERONS OF VARIOUS AILERON PLAN FORMS ON THE 51.3° SWEPTBACK WING

Aileron plan form		C_{l_δ}	C_{h_δ}	C_{h_α}	$C_{h_\delta}/C_{l_\delta}$	Aileron span	Effective aileron span
Angle of inboard tip (deg)	Angle of outboard tip (deg)						
20	20	-0.00048	-0.0024	-0.0001	5.00	0.393b/2	0.383b/2
0	0	-.00050	-.0031	-.0002	6.20	.393b/2	.393b/2
-41.7	-41.7	-.00060	-.0038	-.0005	6.33	.393b/2	.403b/2
-80	-80	-.00054	-.0028	-.0004	5.18	.393b/2	.413b/2
20	0	-.00038	-.0026	-.0002	6.84	.393b/2	.359b/2
-20	0	-.00060	-.0035	-.0004	5.83	.393b/2	.411b/2
-41.7	0	-.00068	-.0038	-.0004	5.59	.393b/2	.427b/2
-80	0	-.00068	-.0035	-.0002	5.16	.393b/2	.459b/2
0	20	-.00053	-.0032	-.0004	6.04	.393b/2	.417b/2
0	-41.7	-.00047	-.0030	-.0003	5.32	.393b/2	.369b/2
0	-80	-.00042	-.0025	-.0004	5.95	.393b/2	.347b/2
-80	20	-.00070	-.0030	-.0004	4.28	.393b/2	.483b/2
20	-80	-.00042	-.0022	-.0004	5.24	.393b/2	.313b/2

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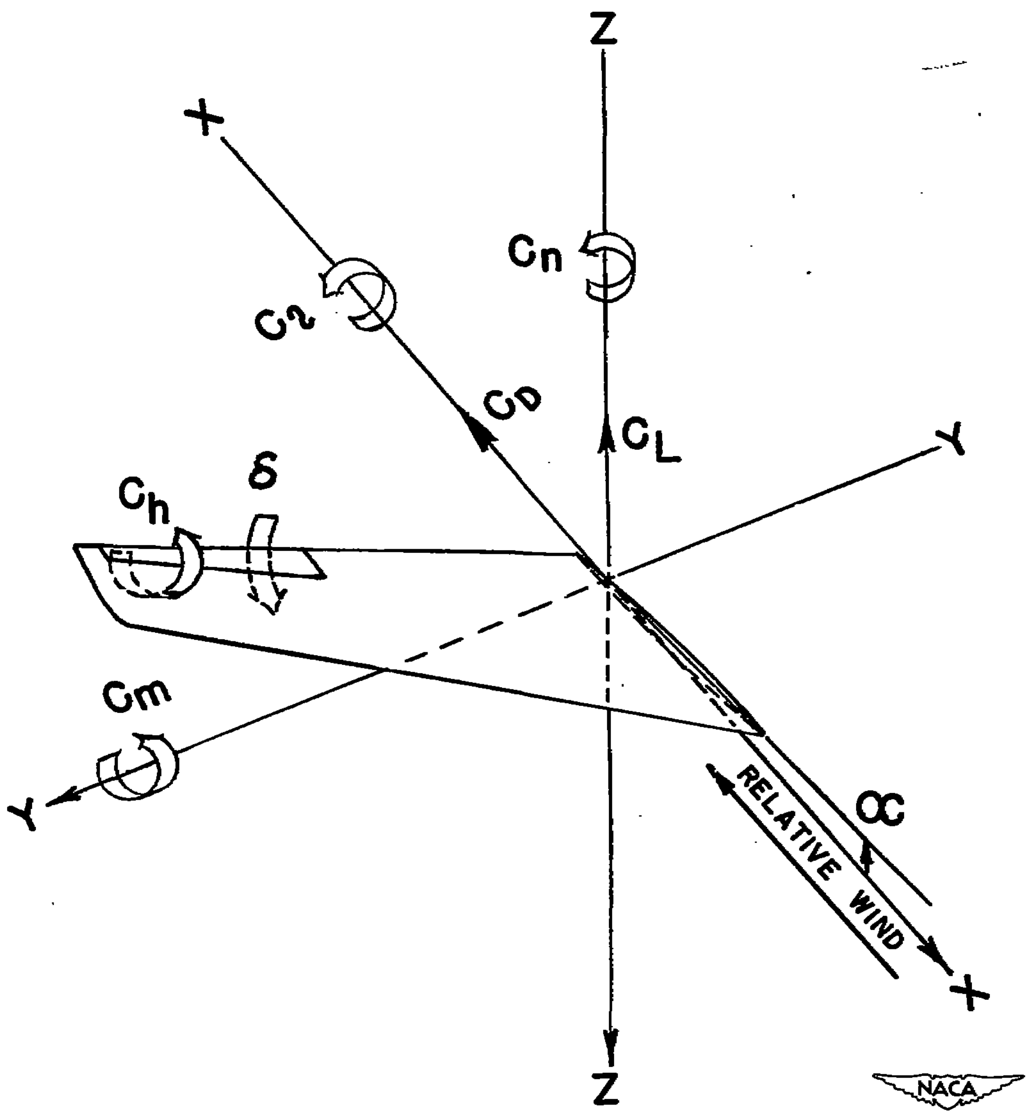

Figure 1.- System of axes, control-surface hinge moments, and deflections. Positive directions of forces, moments, and deflections are indicated by the arrows.

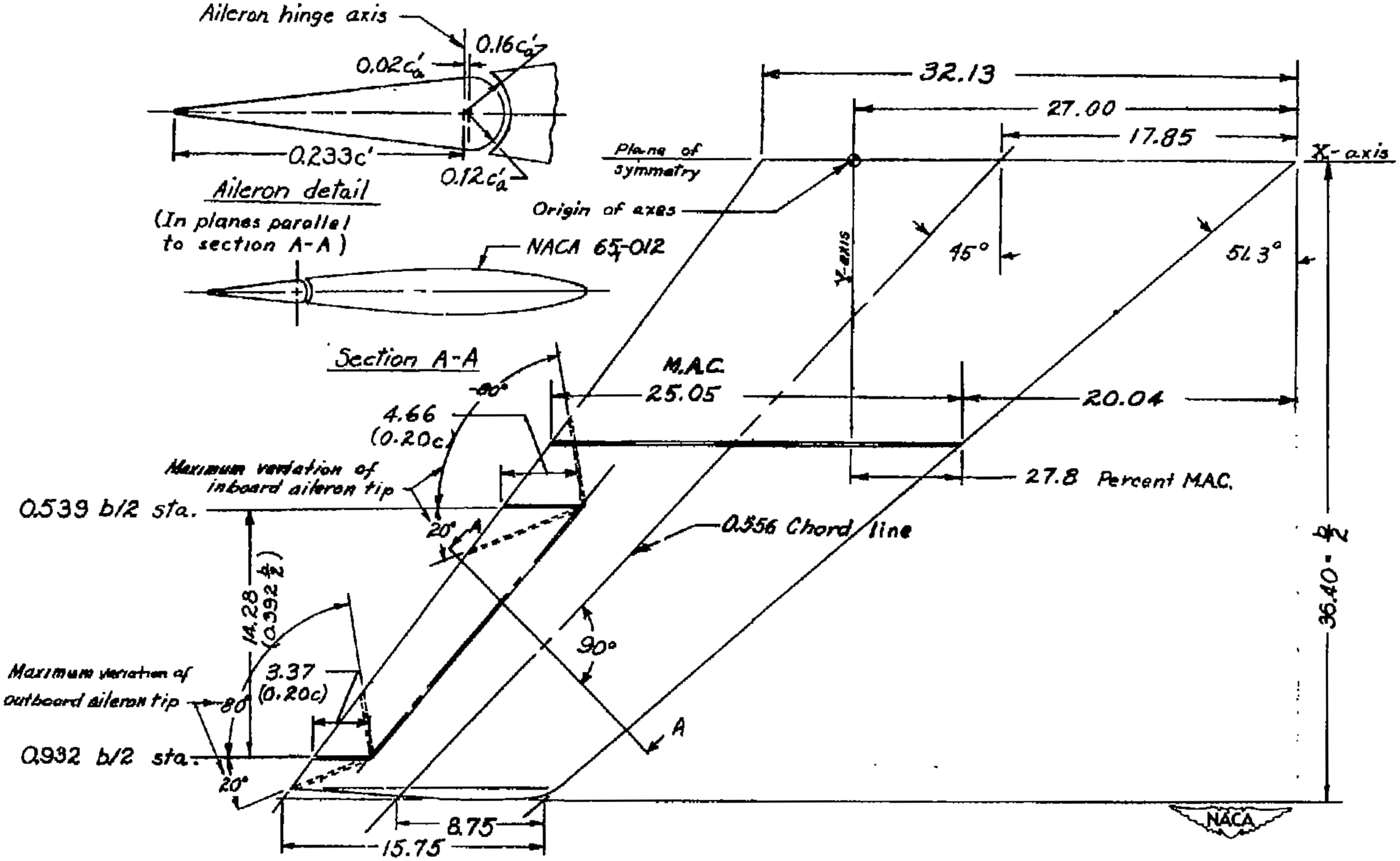

Figure 2.- Drawing of the 51.3° sweptback semispan-wing model showing range of aileron tips investigated. A = 3.06; S = 12.06 square feet; taper ratio, 0.49. (All dimensions are in inches unless otherwise noted.)

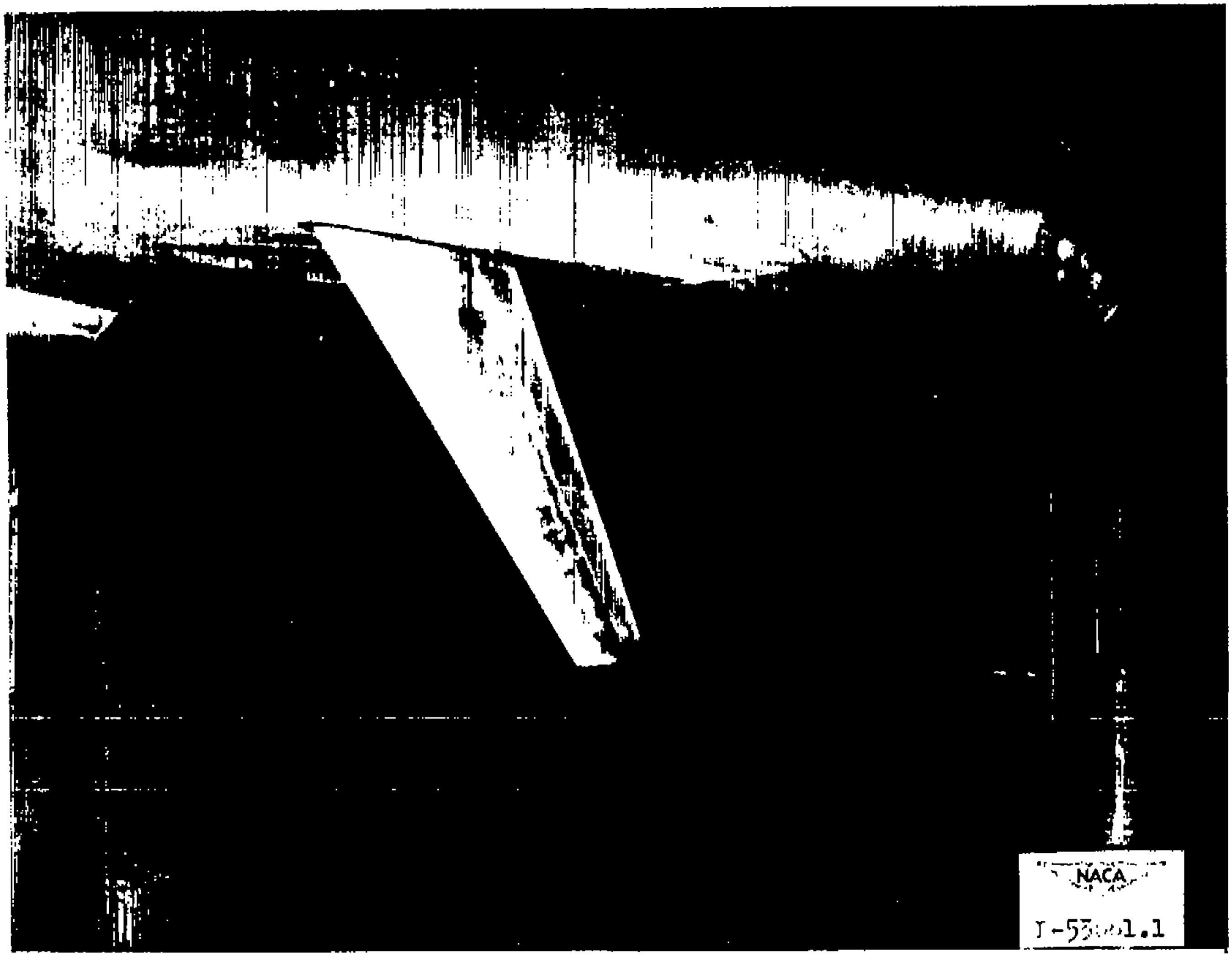

Figure 3.- The 51.3° sweptback semispan-wing model mounted from the ceiling of the Langley 300 MPH 7- by 10-foot tunnel.

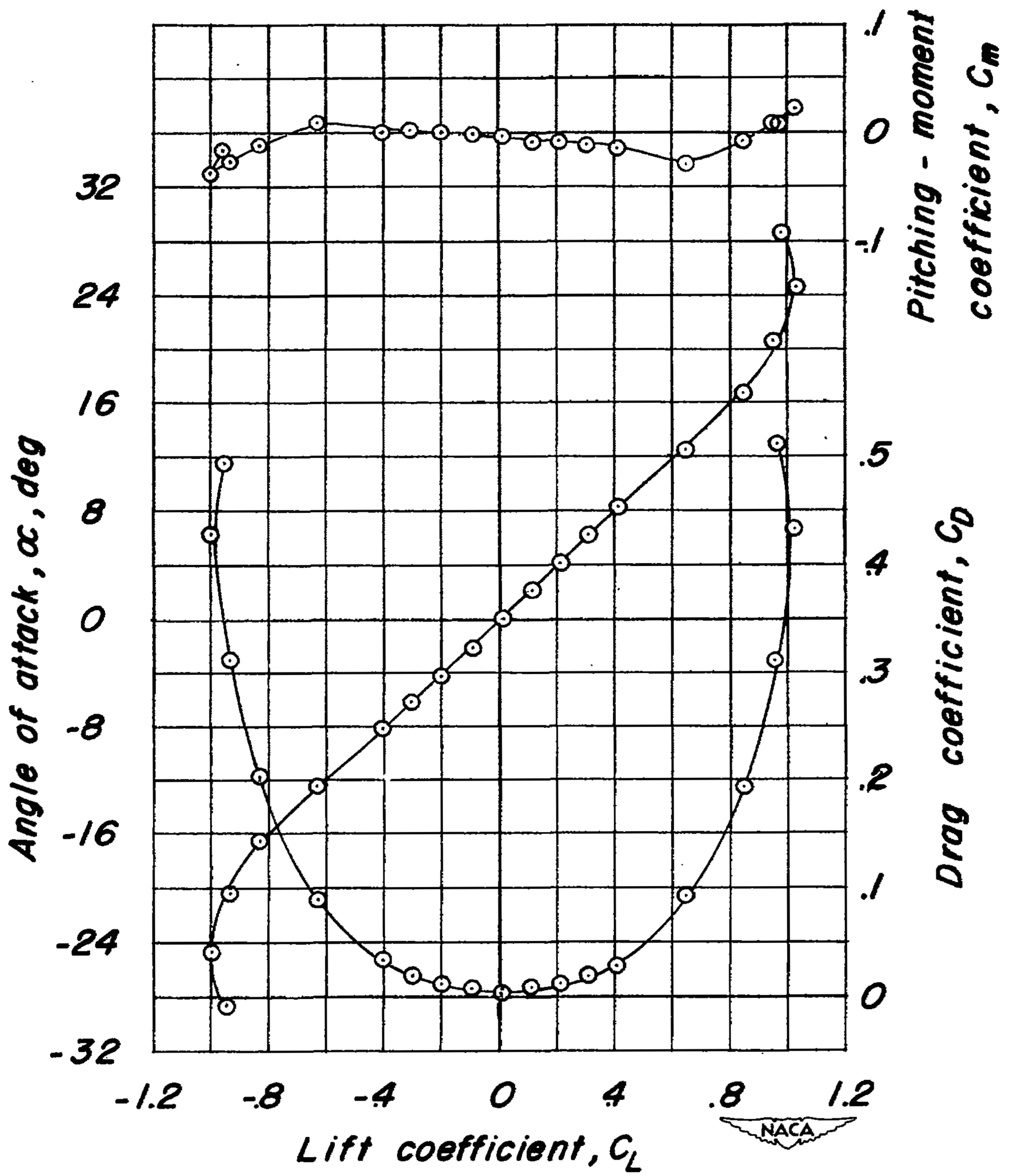

Figure 4.- The aerodynamic characteristics in pitch of the 51.3° sweptback semispan wing with $\delta \approx 0°$.

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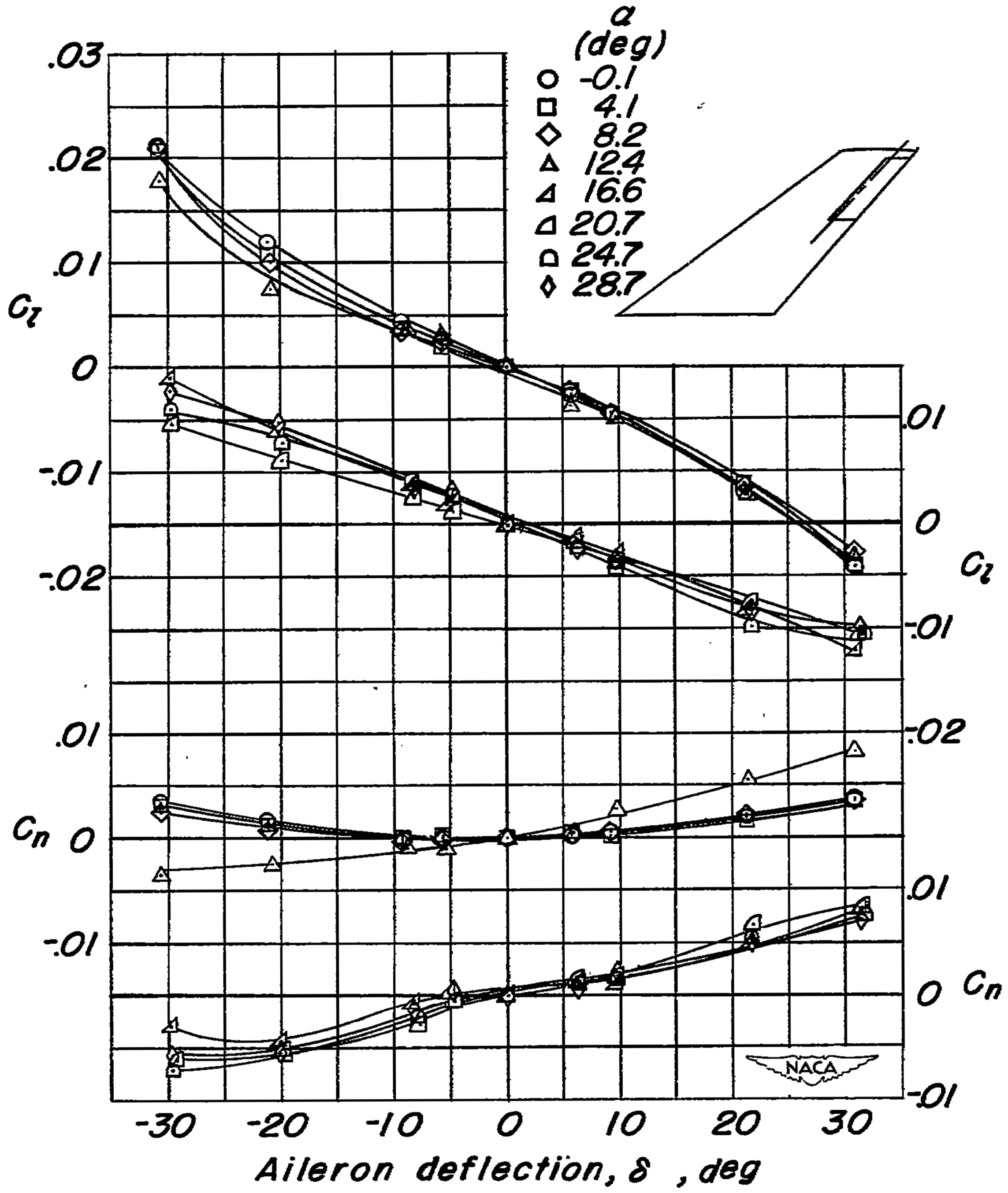

(a) Outboard and inboard aileron tips parallel to the plane of symmetry.

Figure 5.- Variation of lateral-control and hinge-moment characteristics with aileron deflection on the 51.3° sweptback wing with the inboard and outboard aileron tips parallel.

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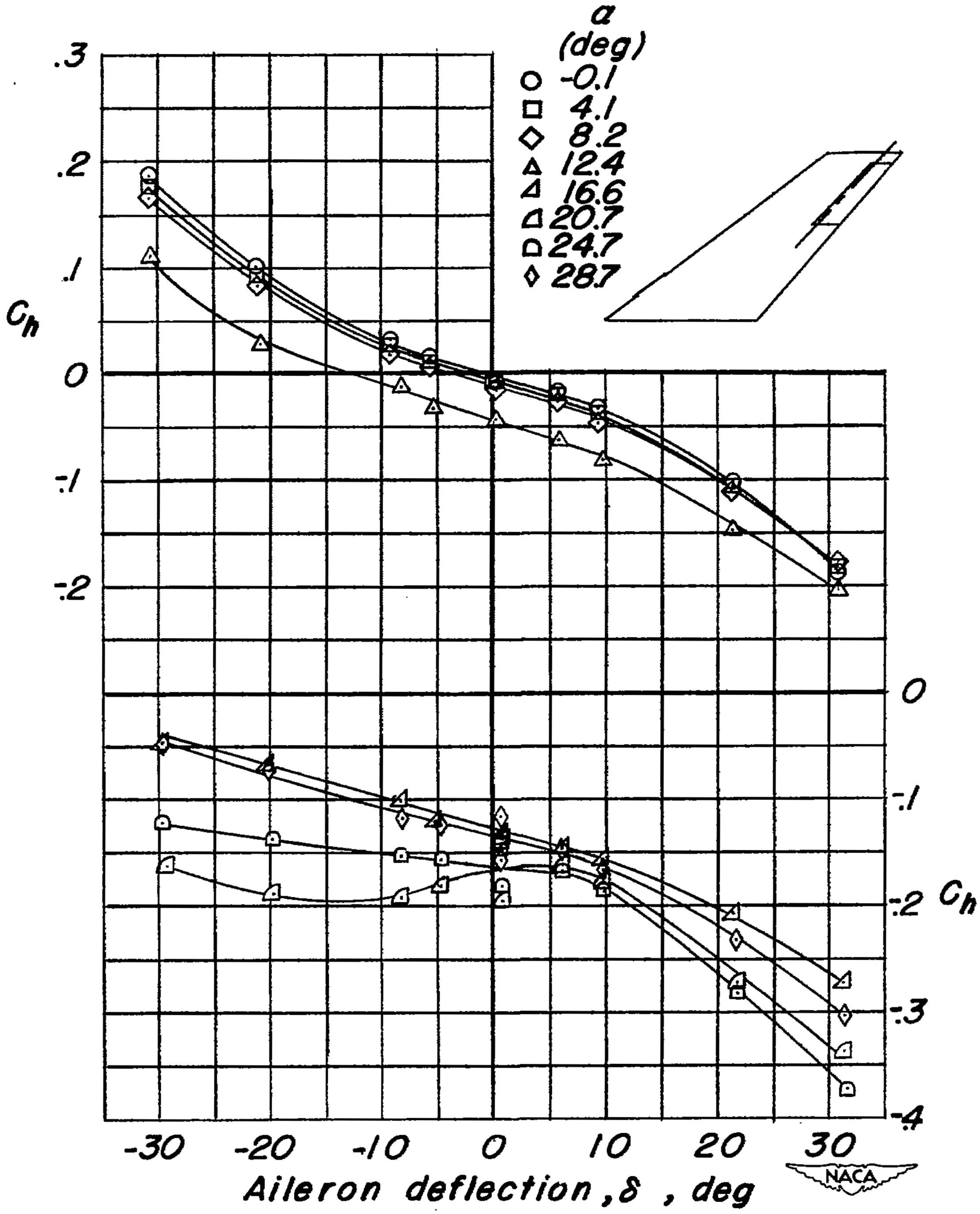

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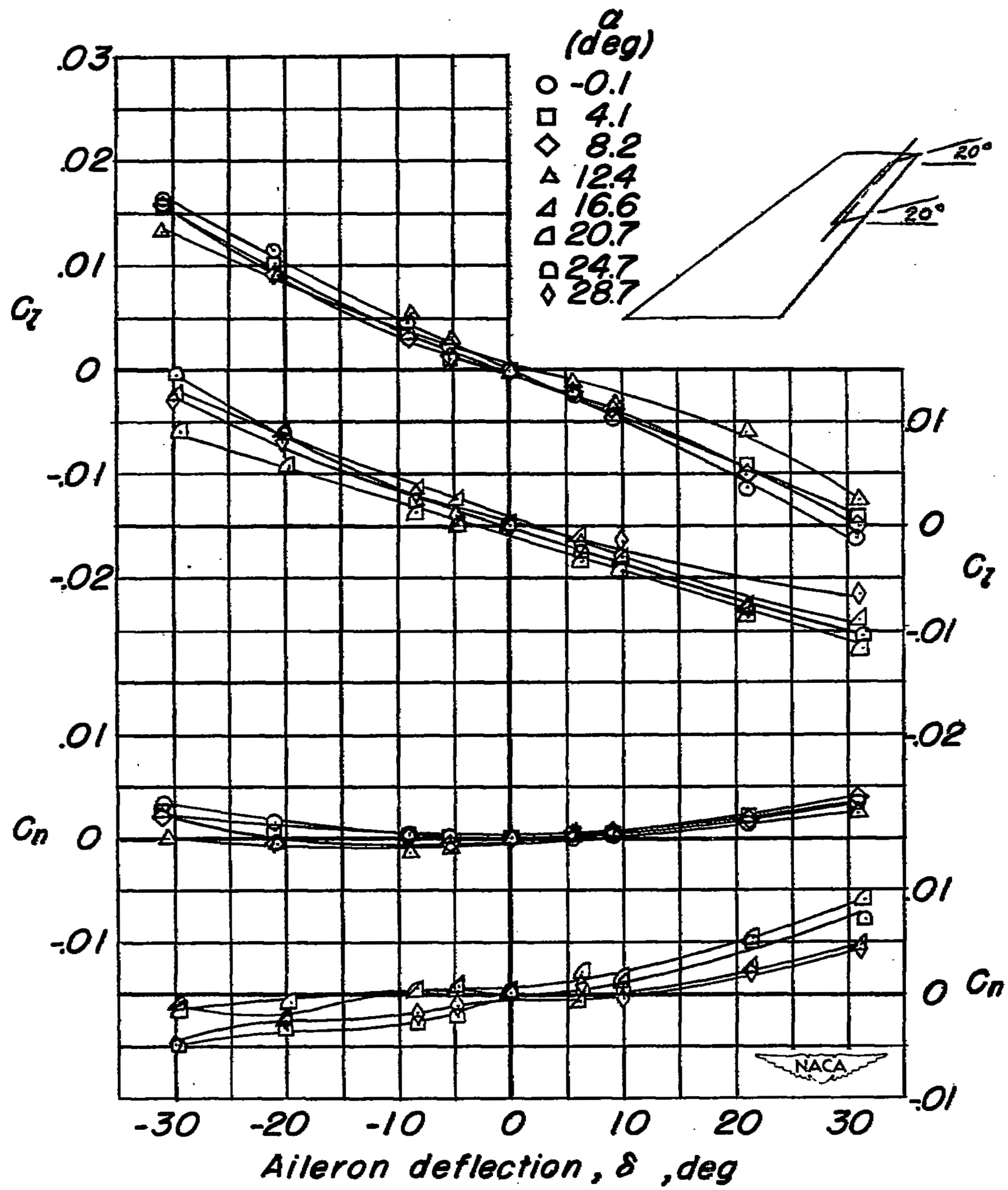
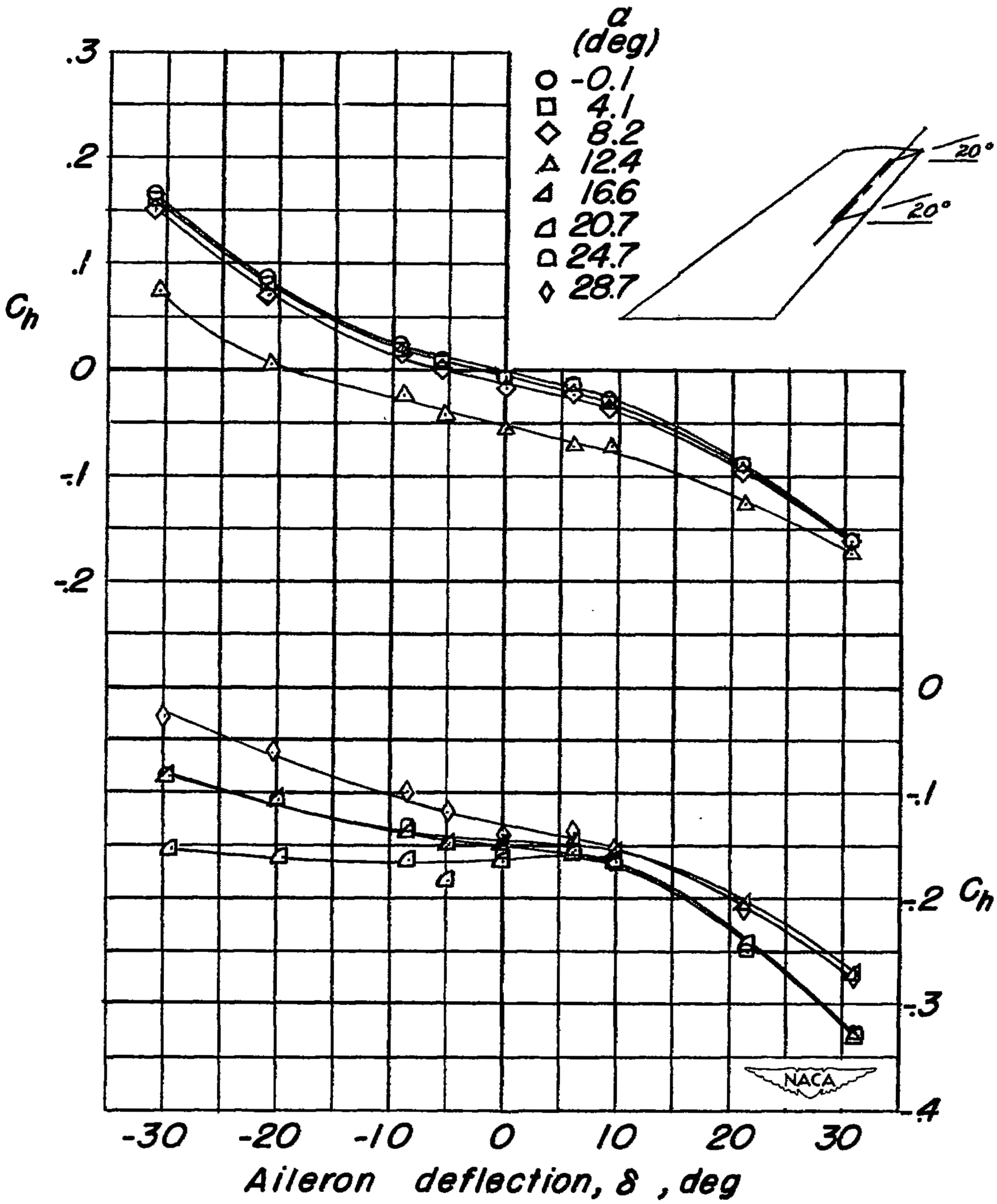
Figure 5.- Continued.



(b) Outboard and inboard aileron tips at an angle of 20°.

Figure 5.- Continued.



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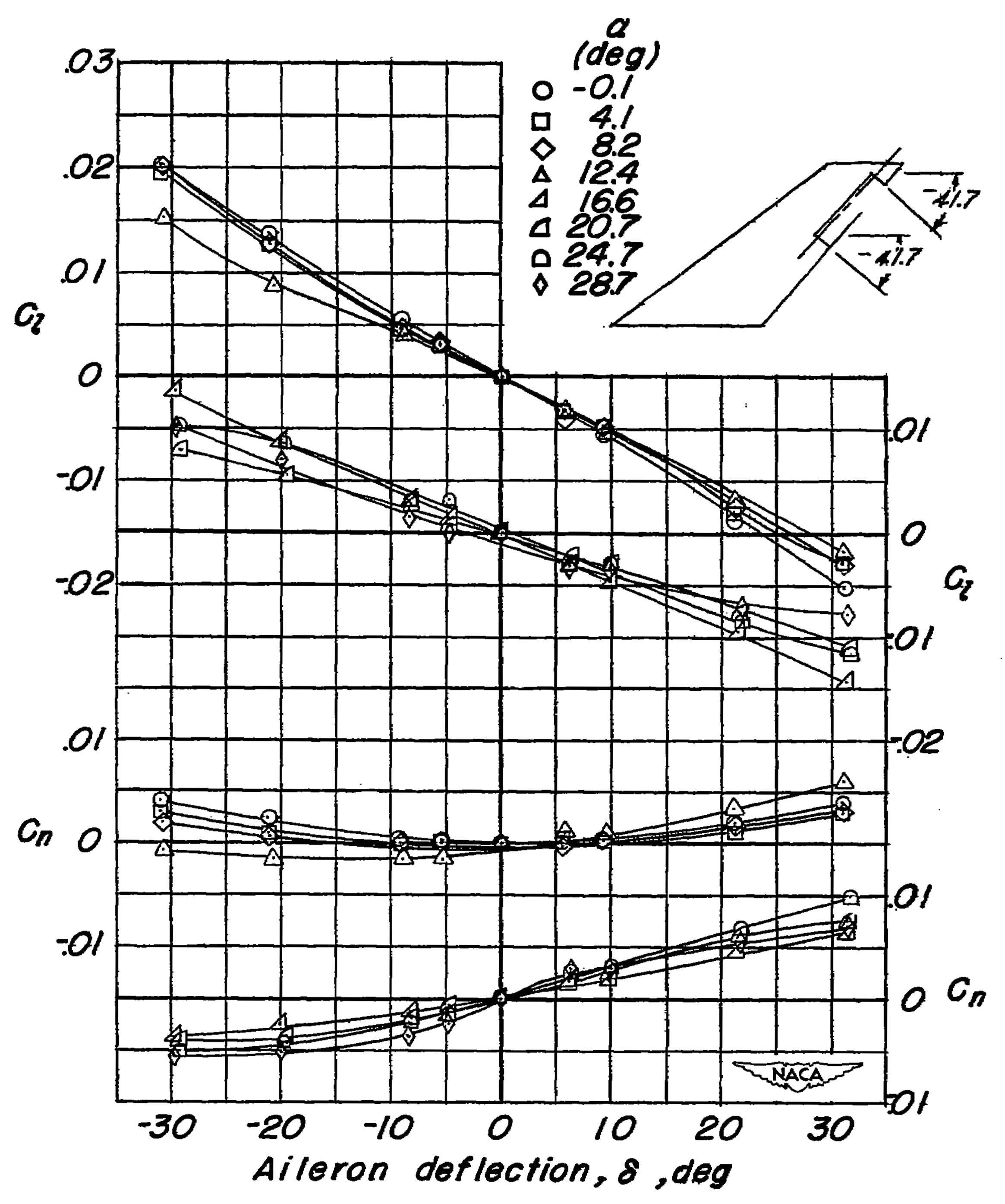
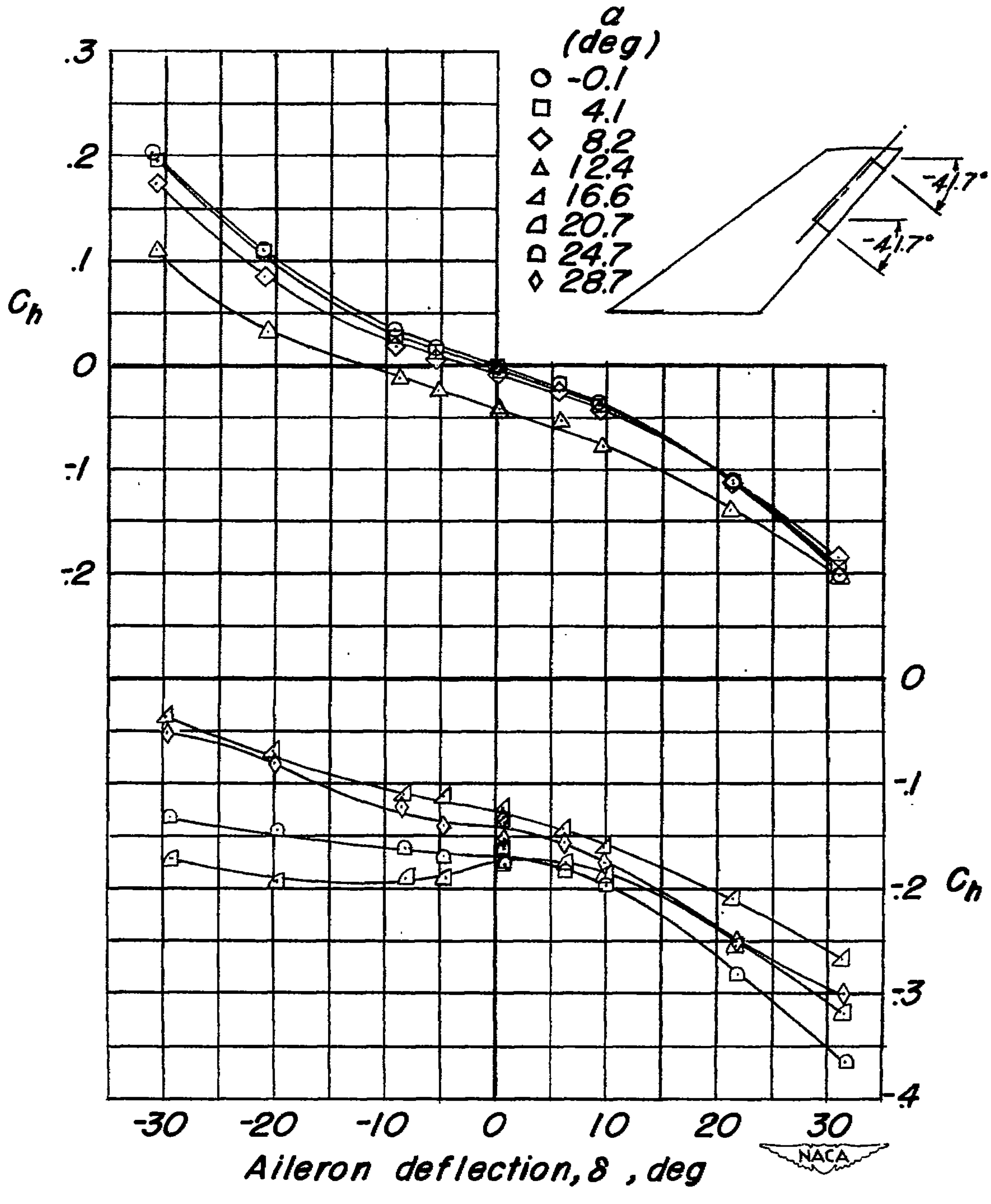


(c) Outboard and inboard aileron tips at an angle of -41.7° (perpendicular to aileron hinge line).

Figure 5.- Continued.



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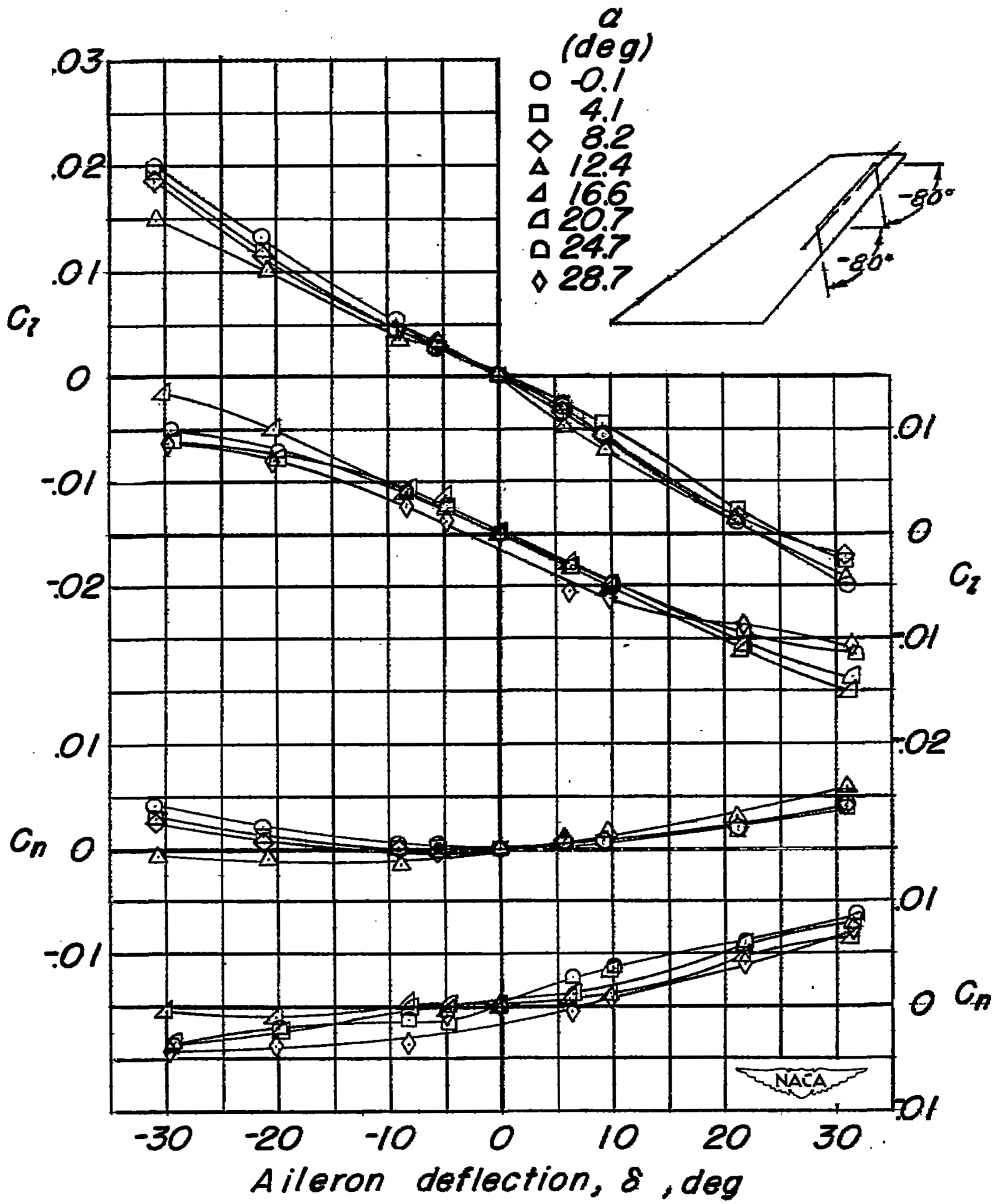

(d) Outboard and inboard aileron tips at an angle of -80°.

Figure 5.- Continued.

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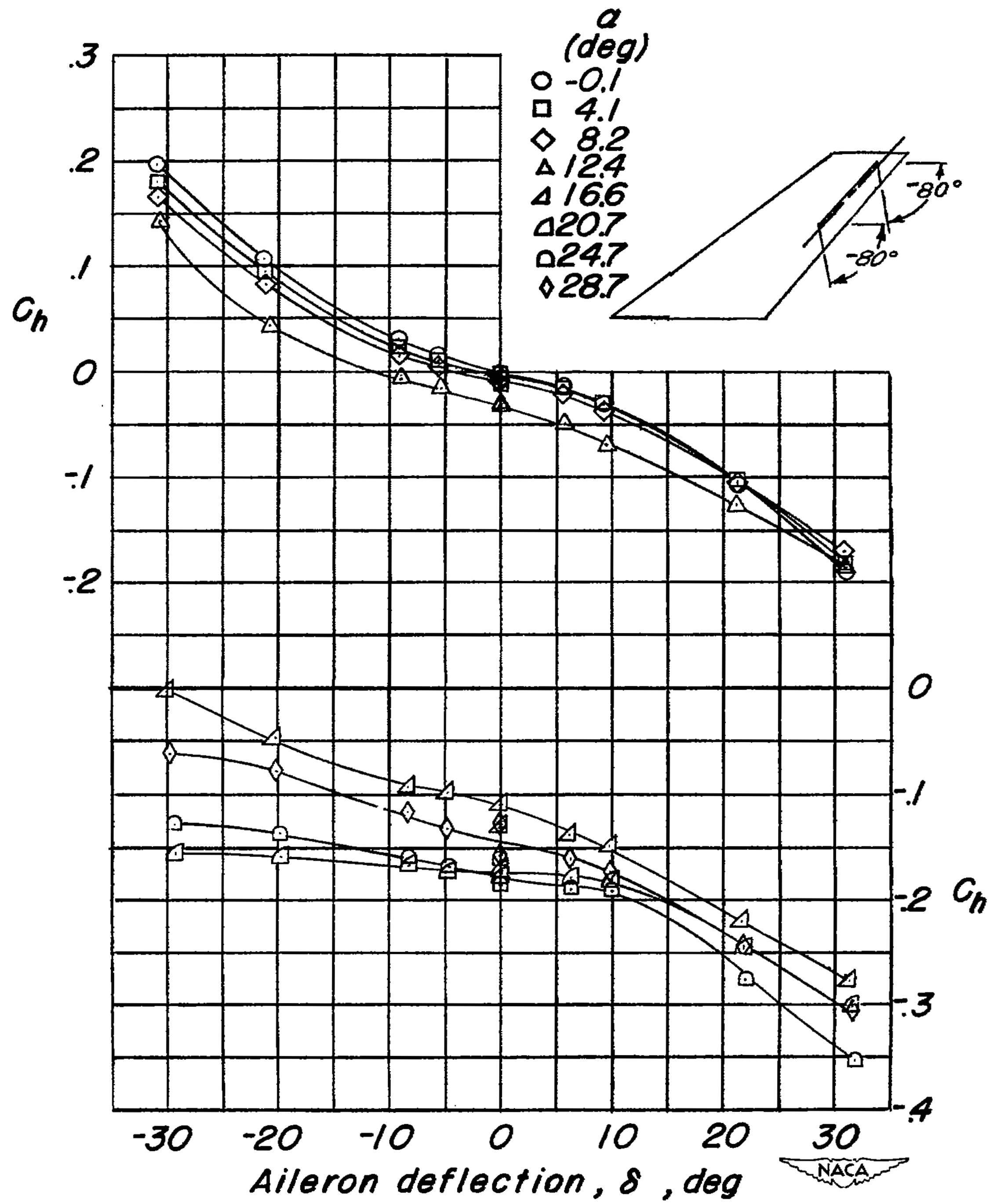

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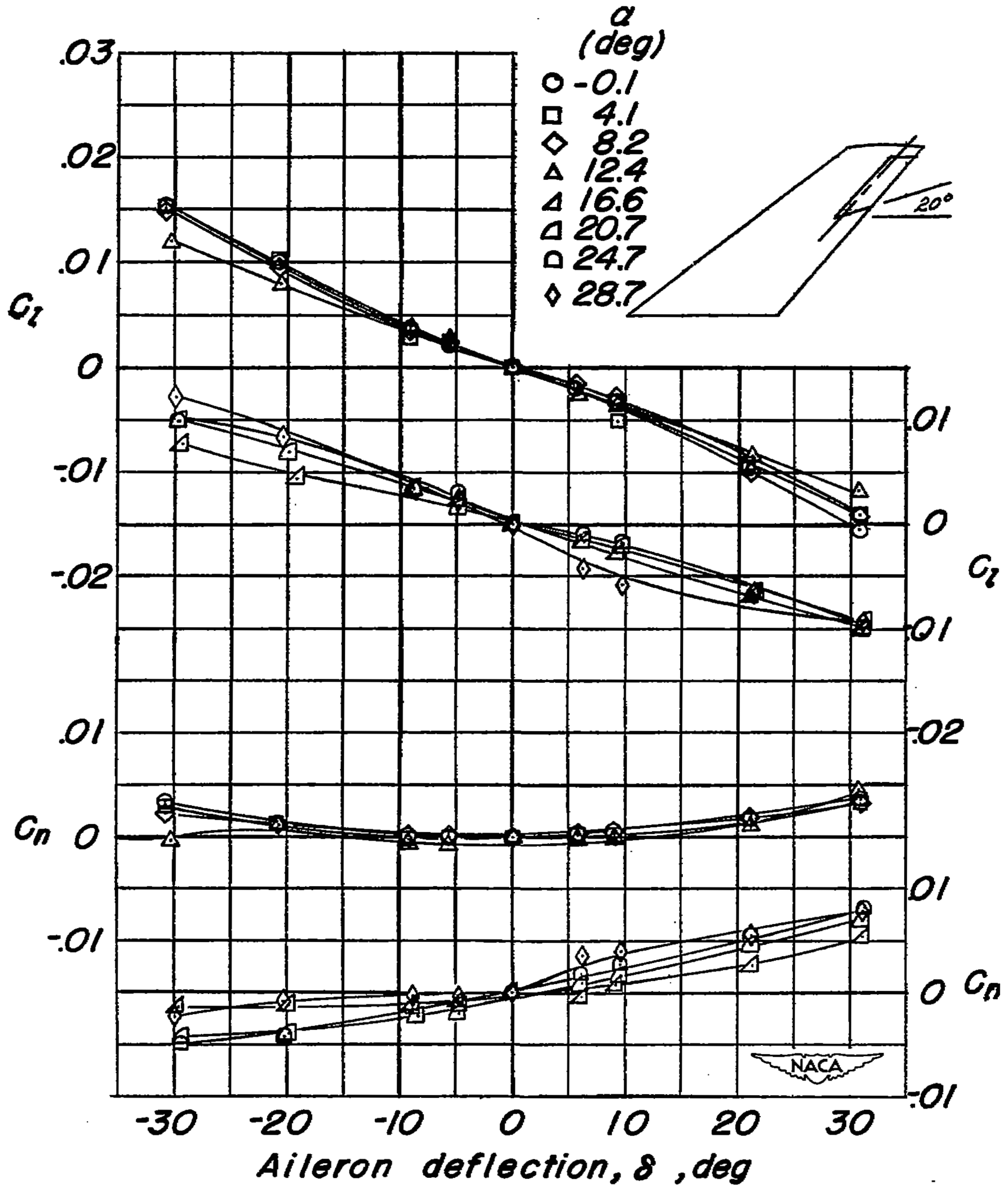

(a) Inboard aileron tip at an angle of 20°.

Figure 6.- Variation of lateral-control and hinge-moment characteristics with aileron deflection on the 51.3° sweptback wing with the outboard aileron tip parallel to the plane of symmetry.

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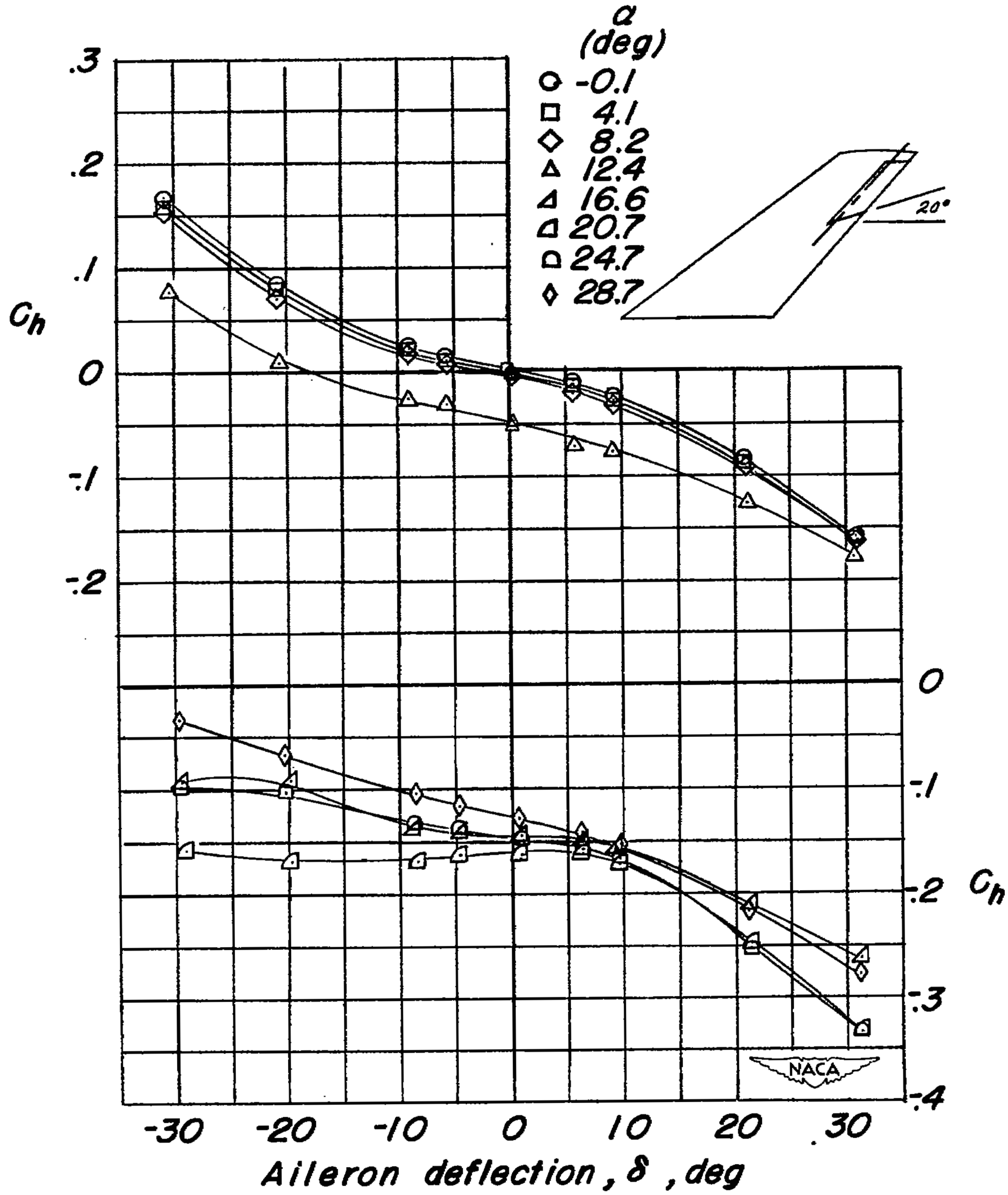

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Figure 6.- Continued.

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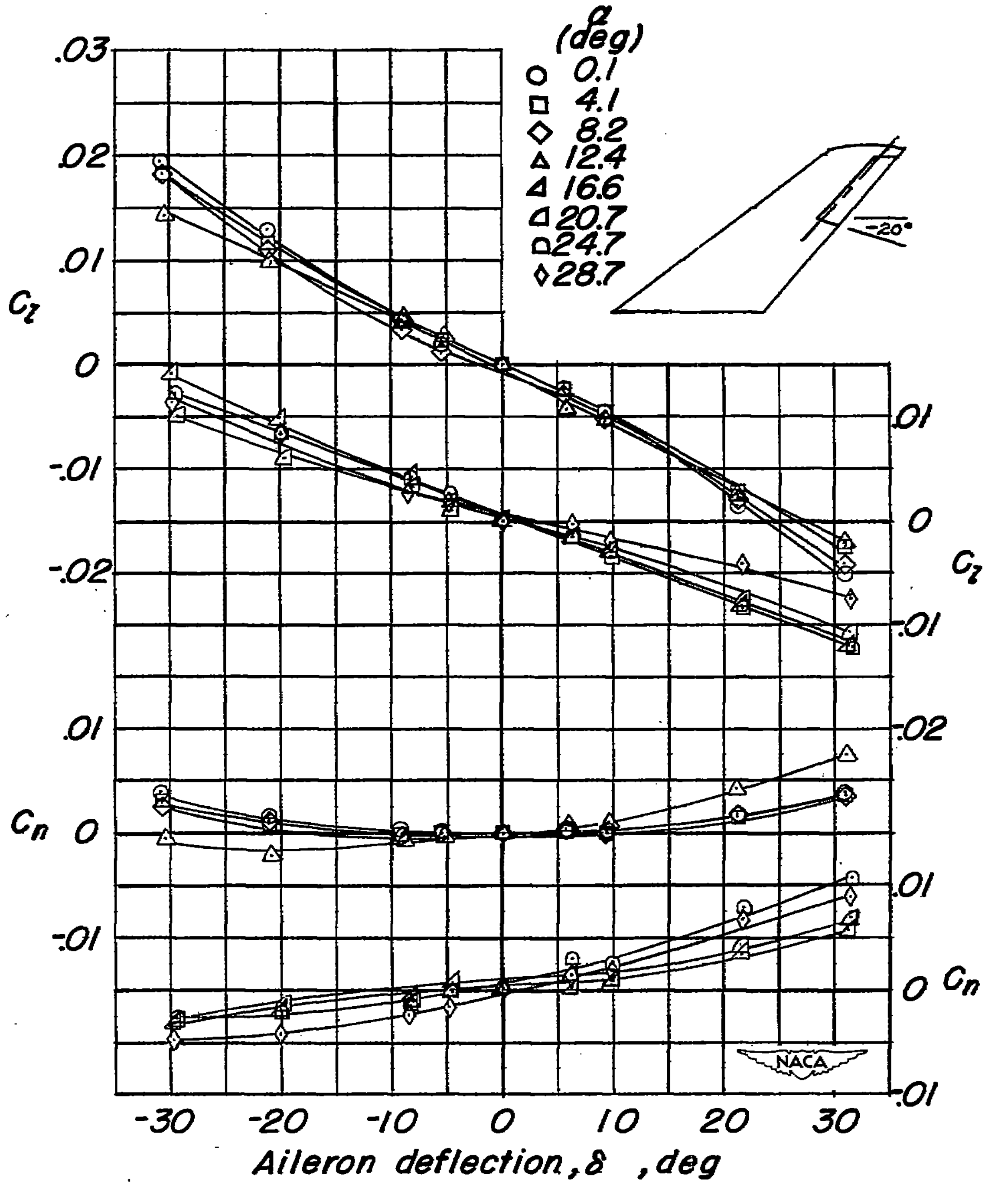

(b) Inboard aileron tip at an angle of -20°.

Figure 6.- Continued.

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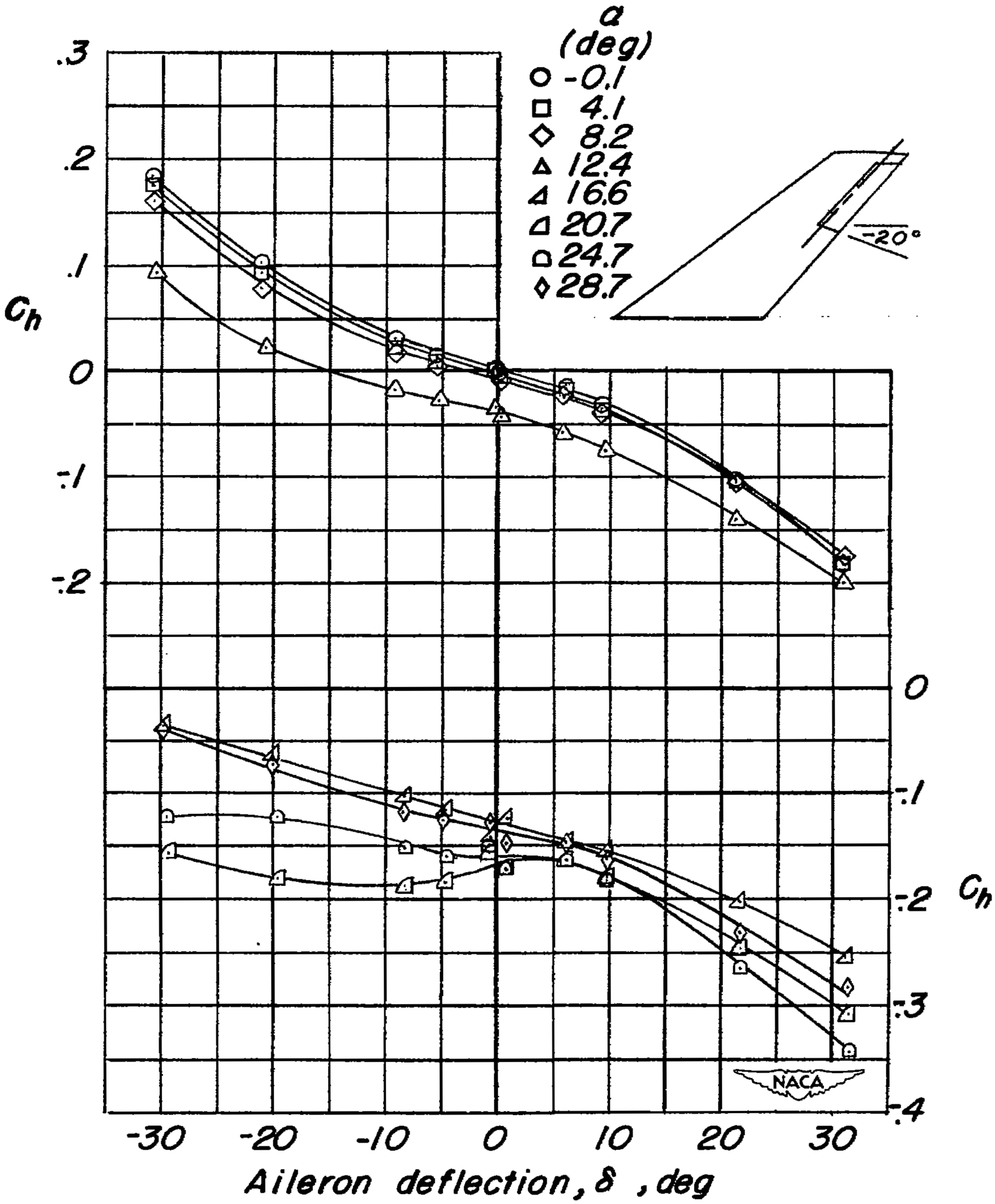

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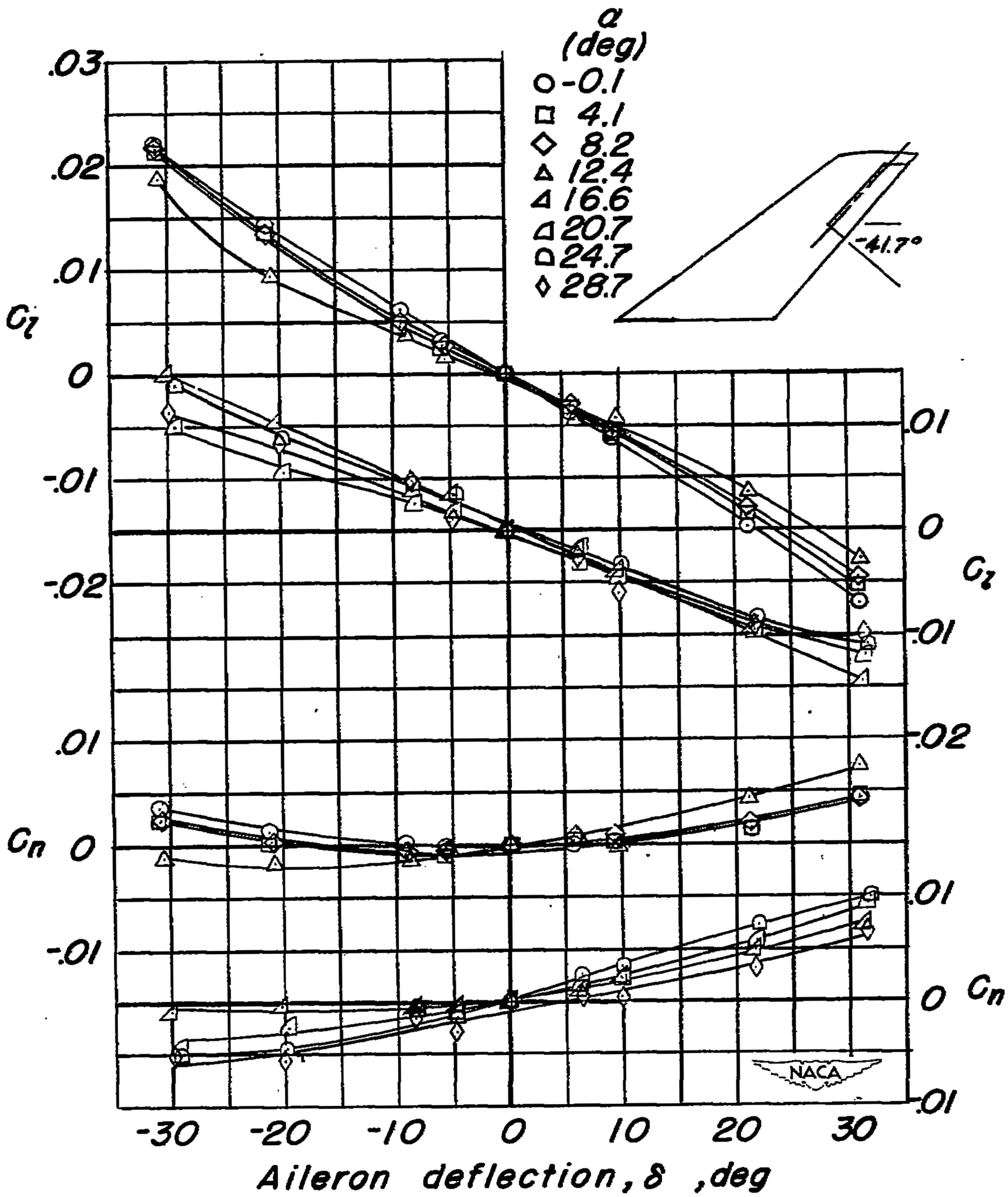
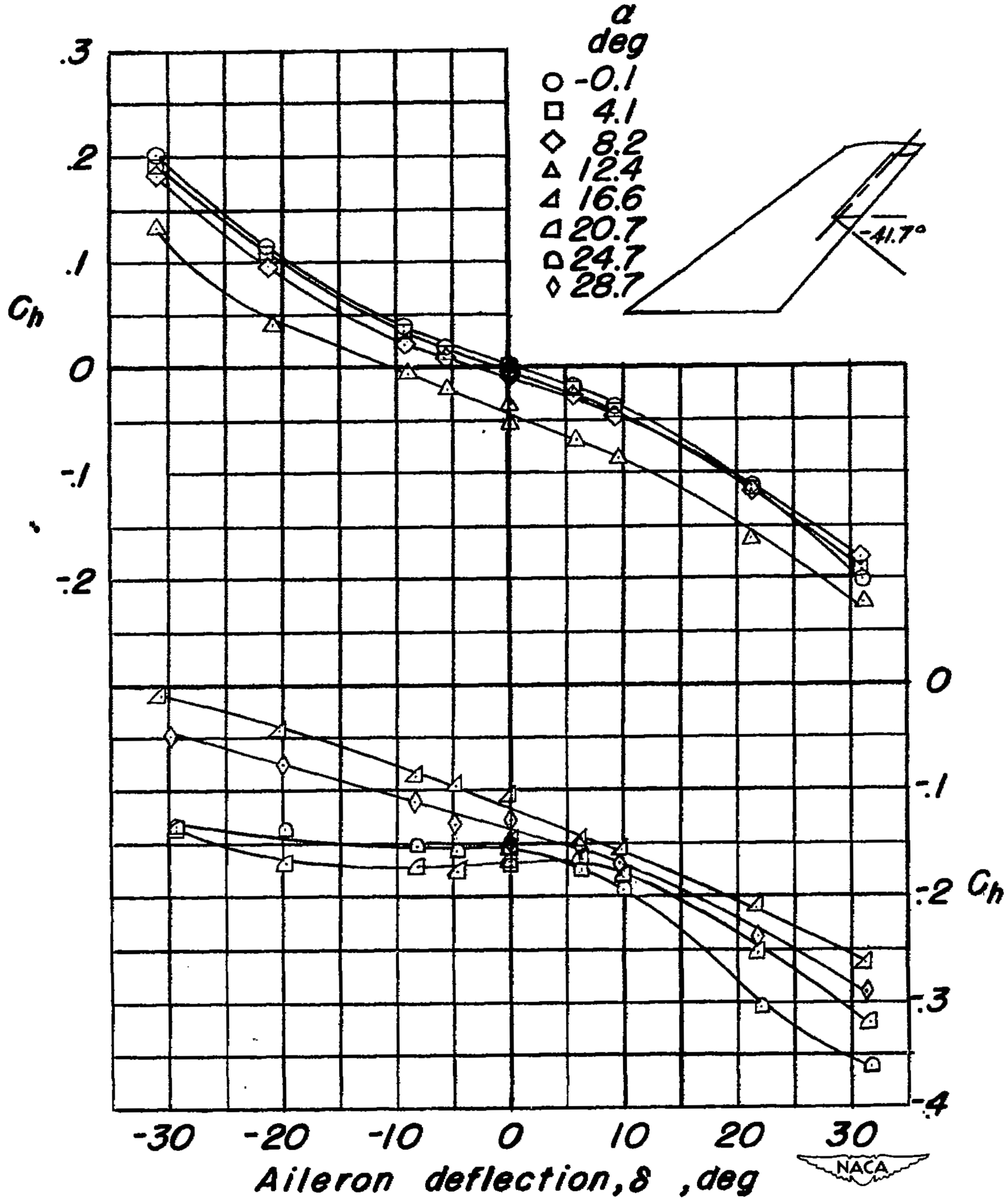


(c) Inboard aileron tip at an angle of -41.7° (perpendicular to aileron hinge line).

Figure 6.- Continued.



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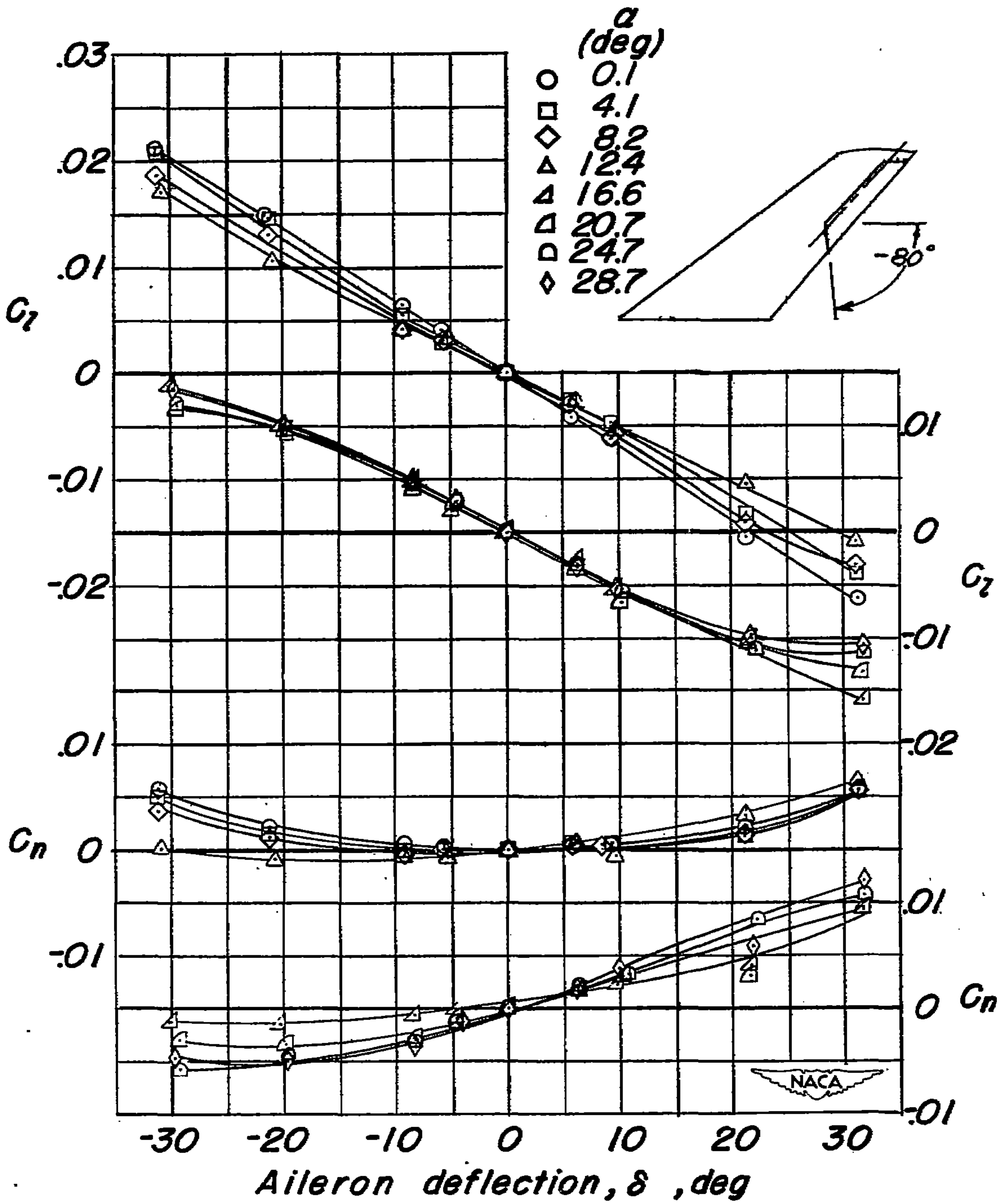
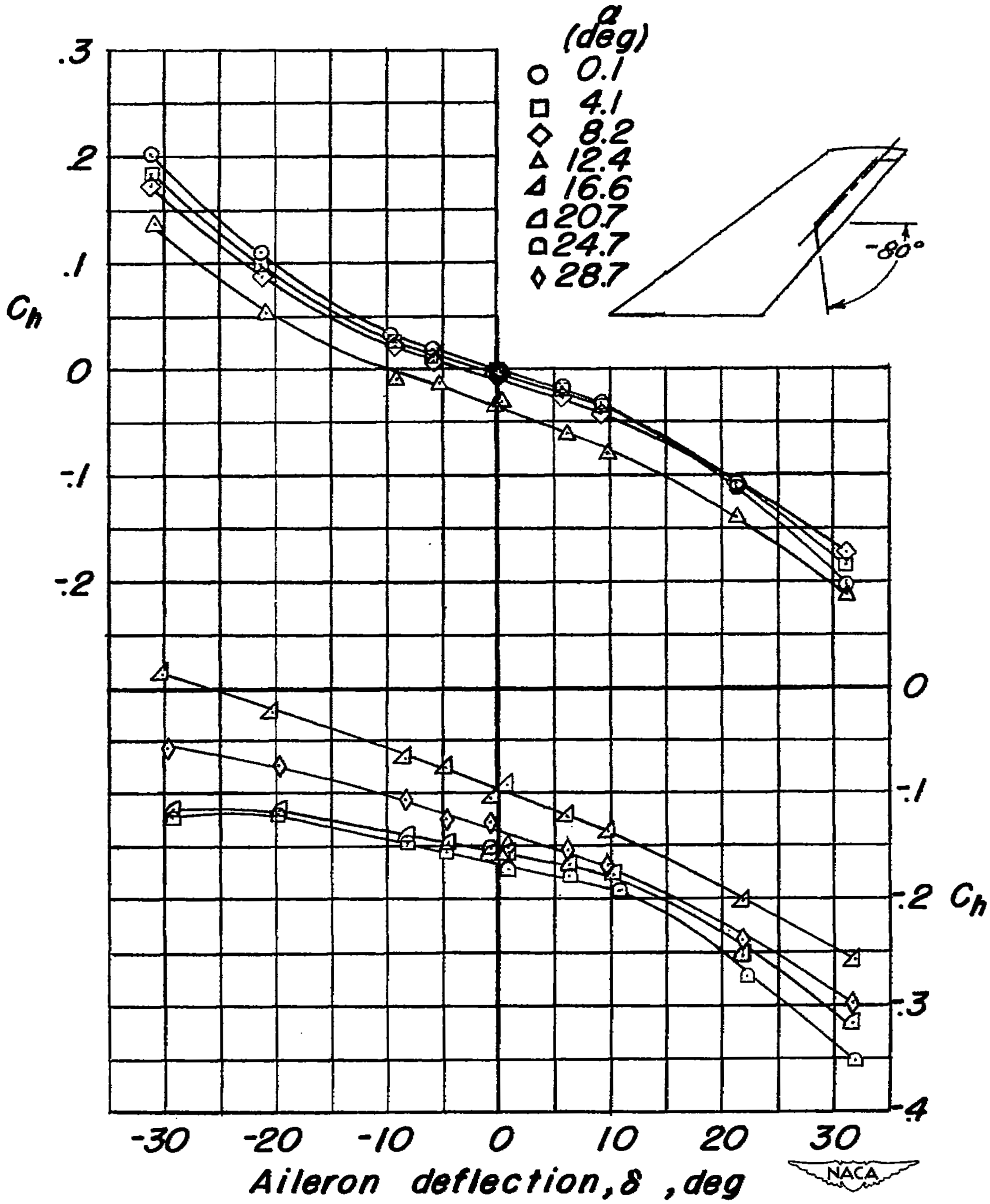


(d) Inboard aileron tip at an angle of -80°.

Figure 6.- Continued.



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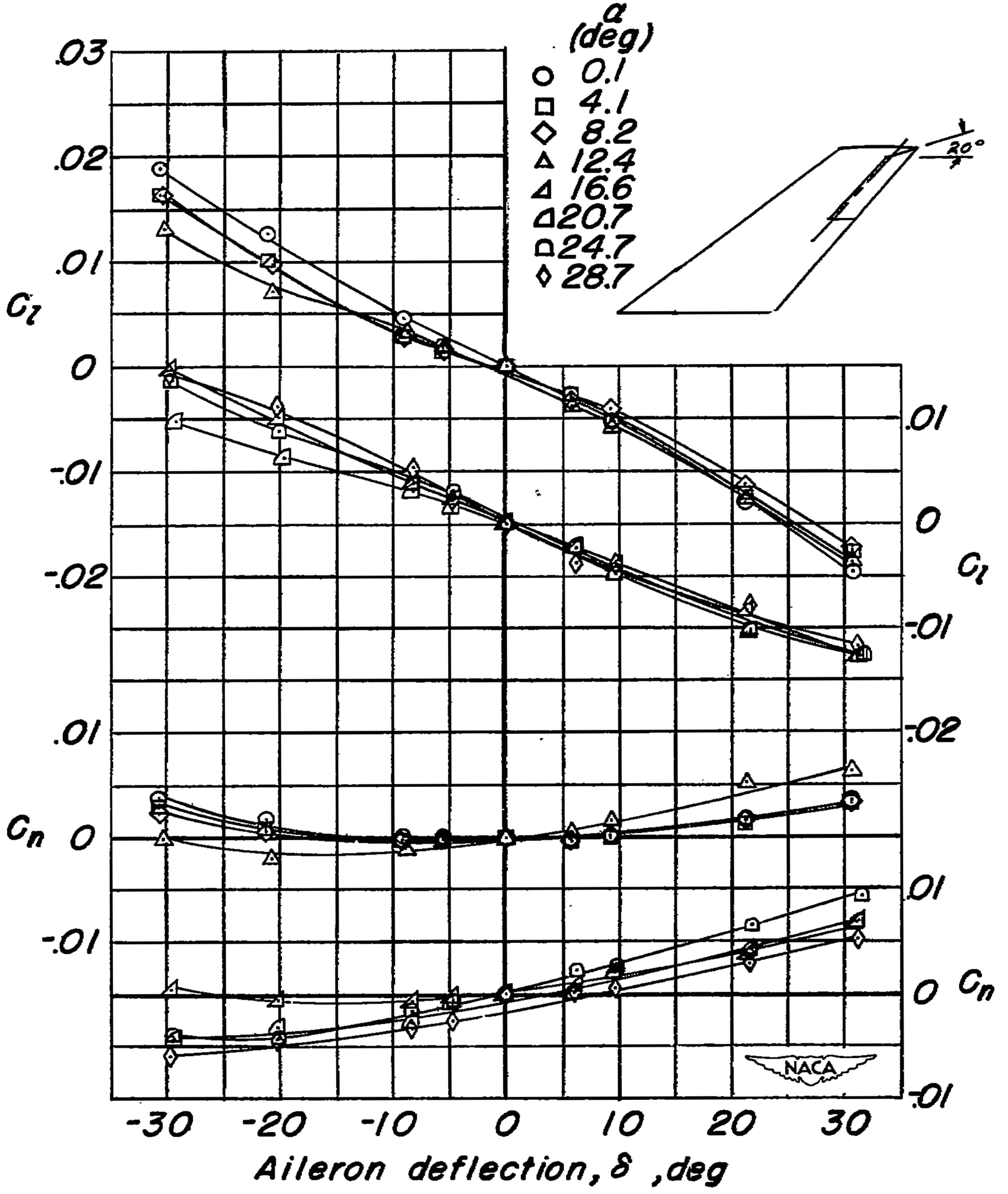
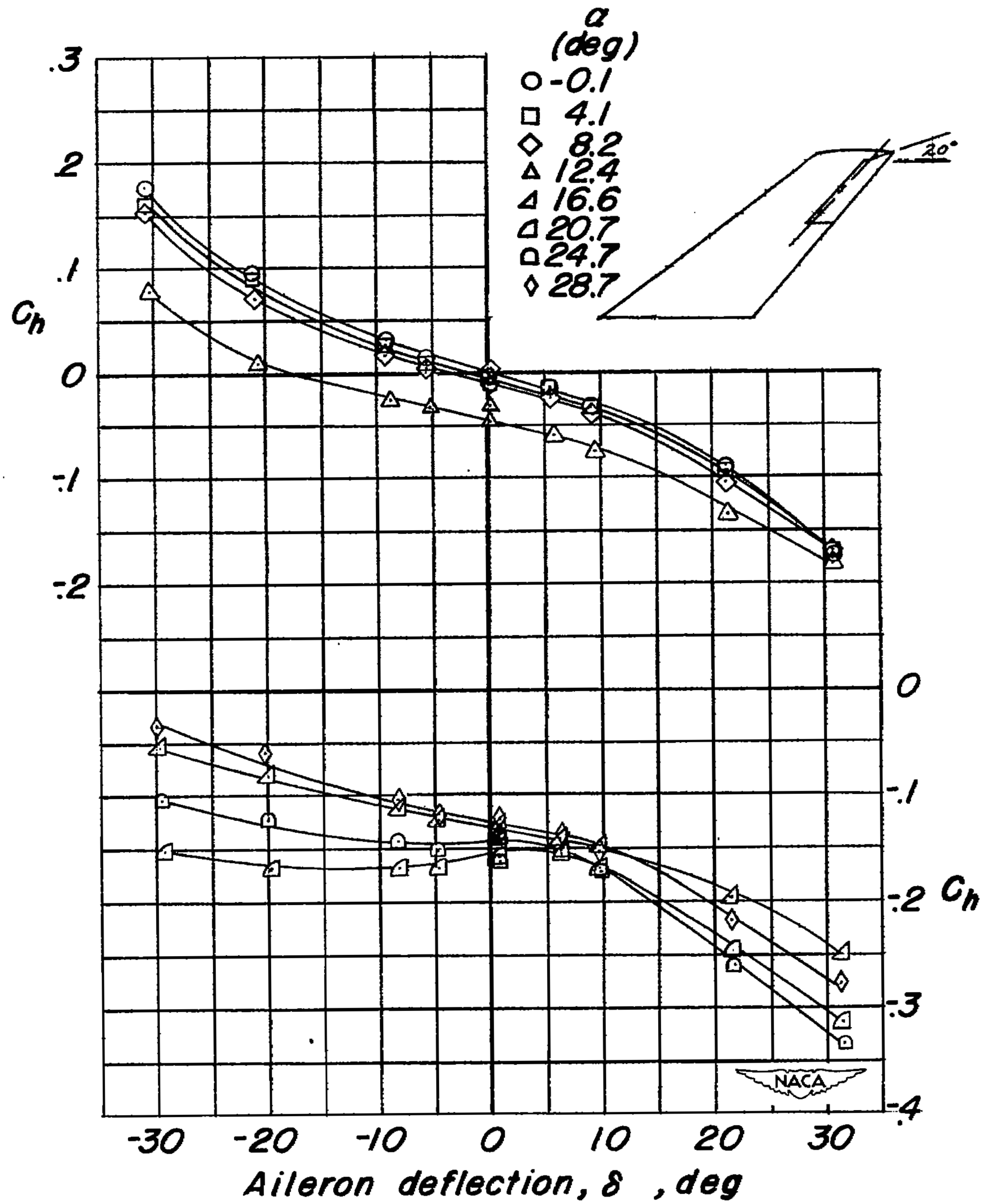


(a) Outboard aileron tip at an angle of 20°.

Figure 7.- Variation of lateral-control and hinge-moment characteristics with aileron deflection on the 51.3° sweptback wing with the inboard aileron tip parallel to the plane of symmetry.



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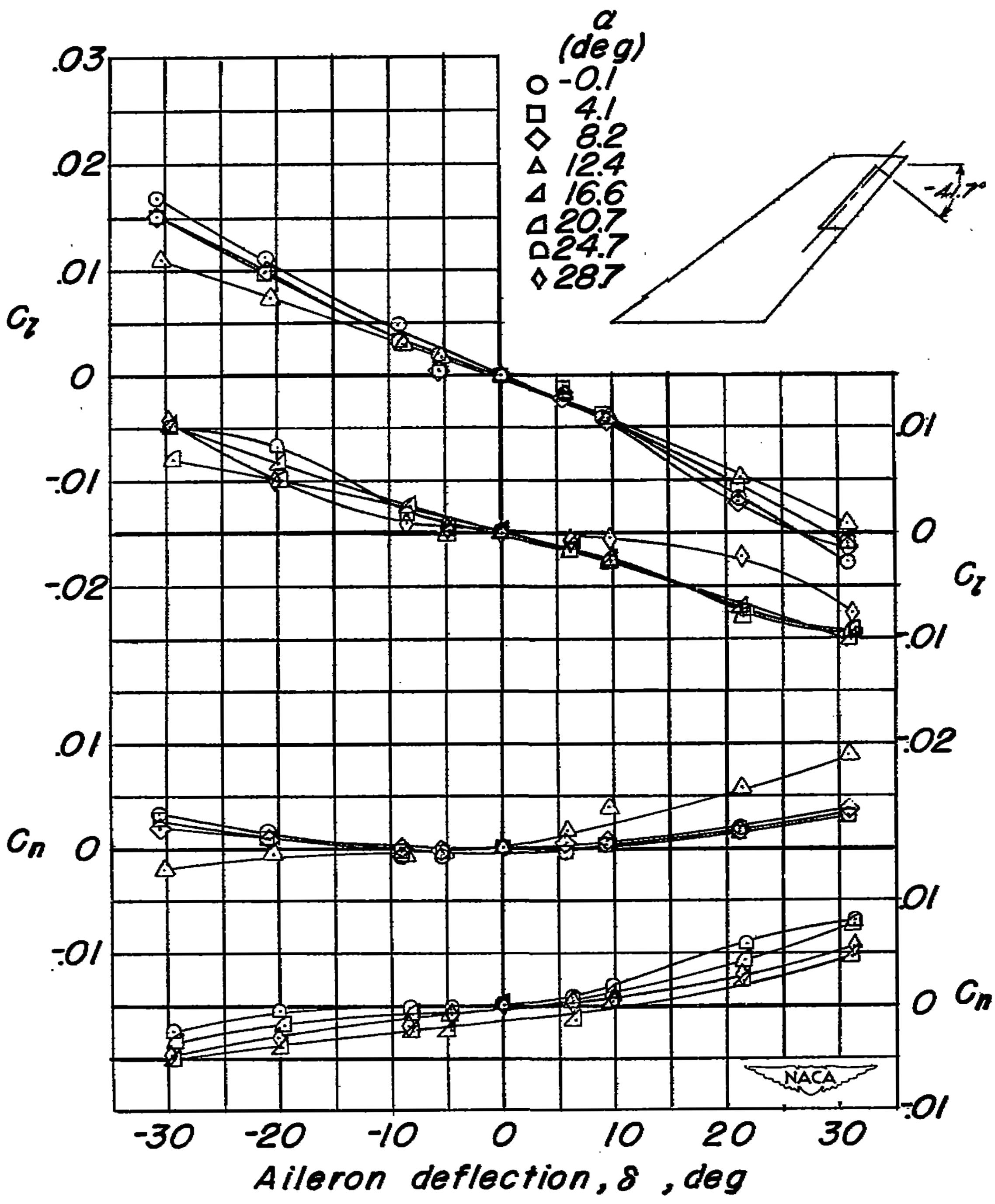
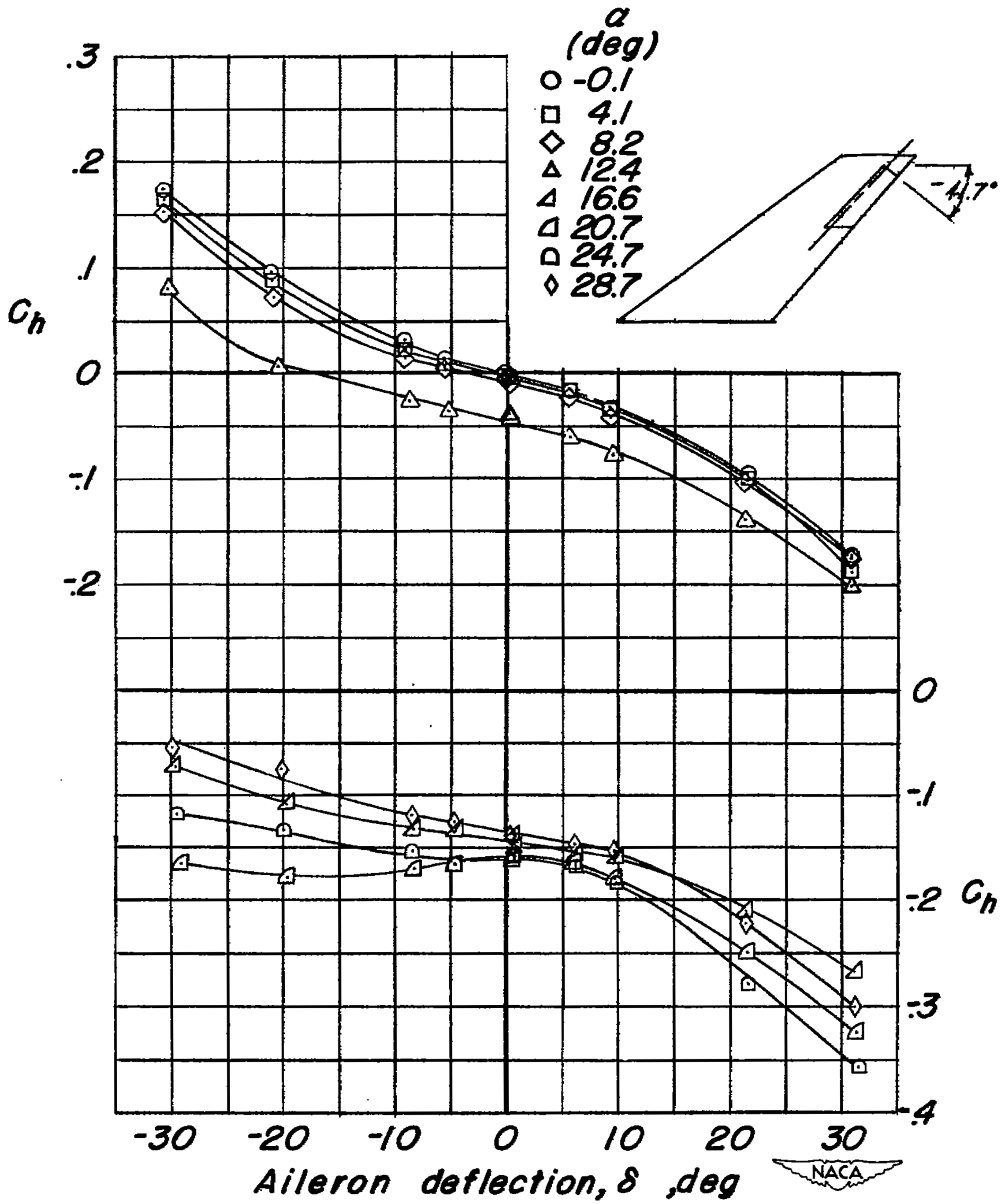


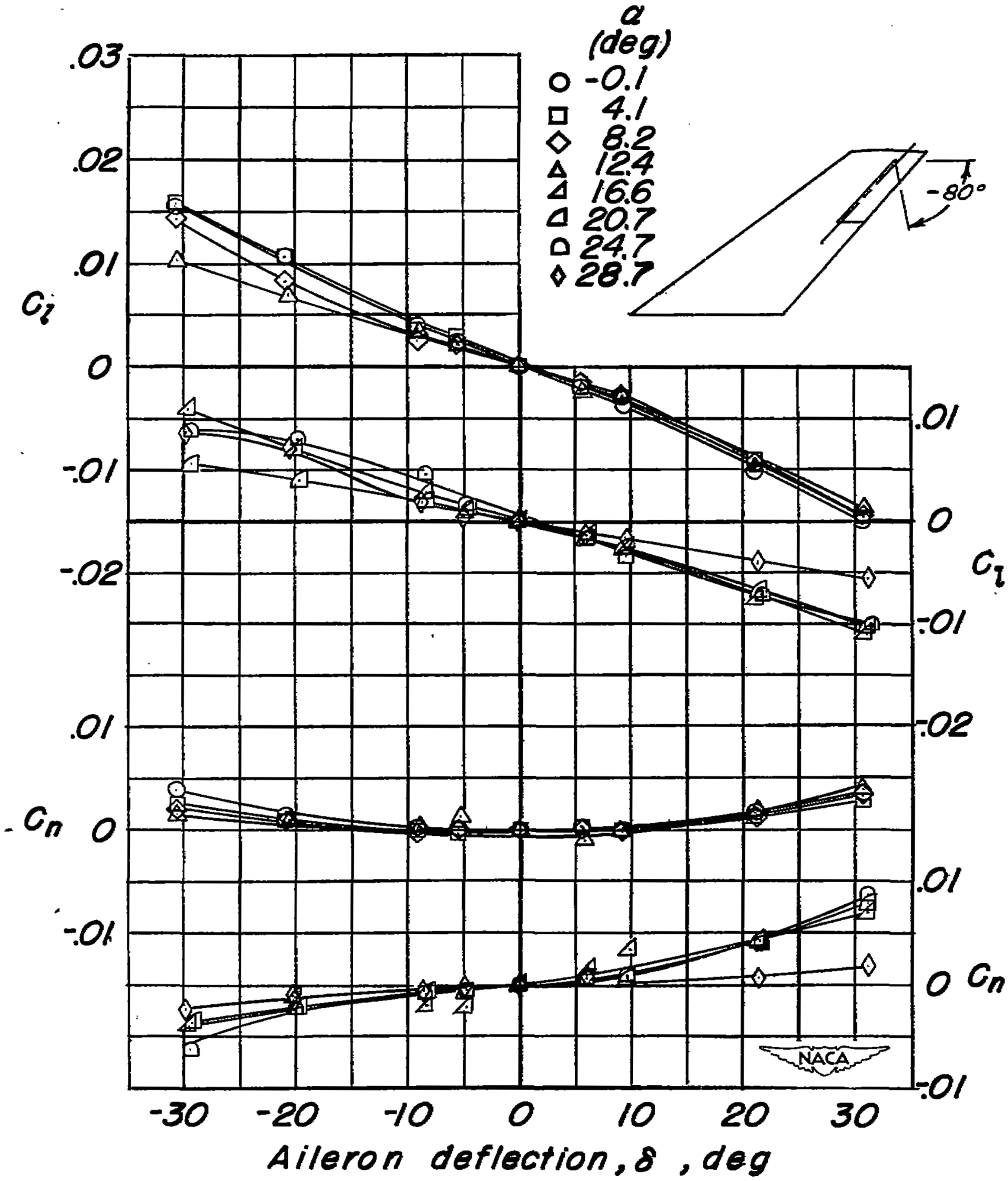
(b) Outboard aileron tip at an angle of -41.7° (perpendicular to the aileron hinge line).

Figure 7.- Continued.



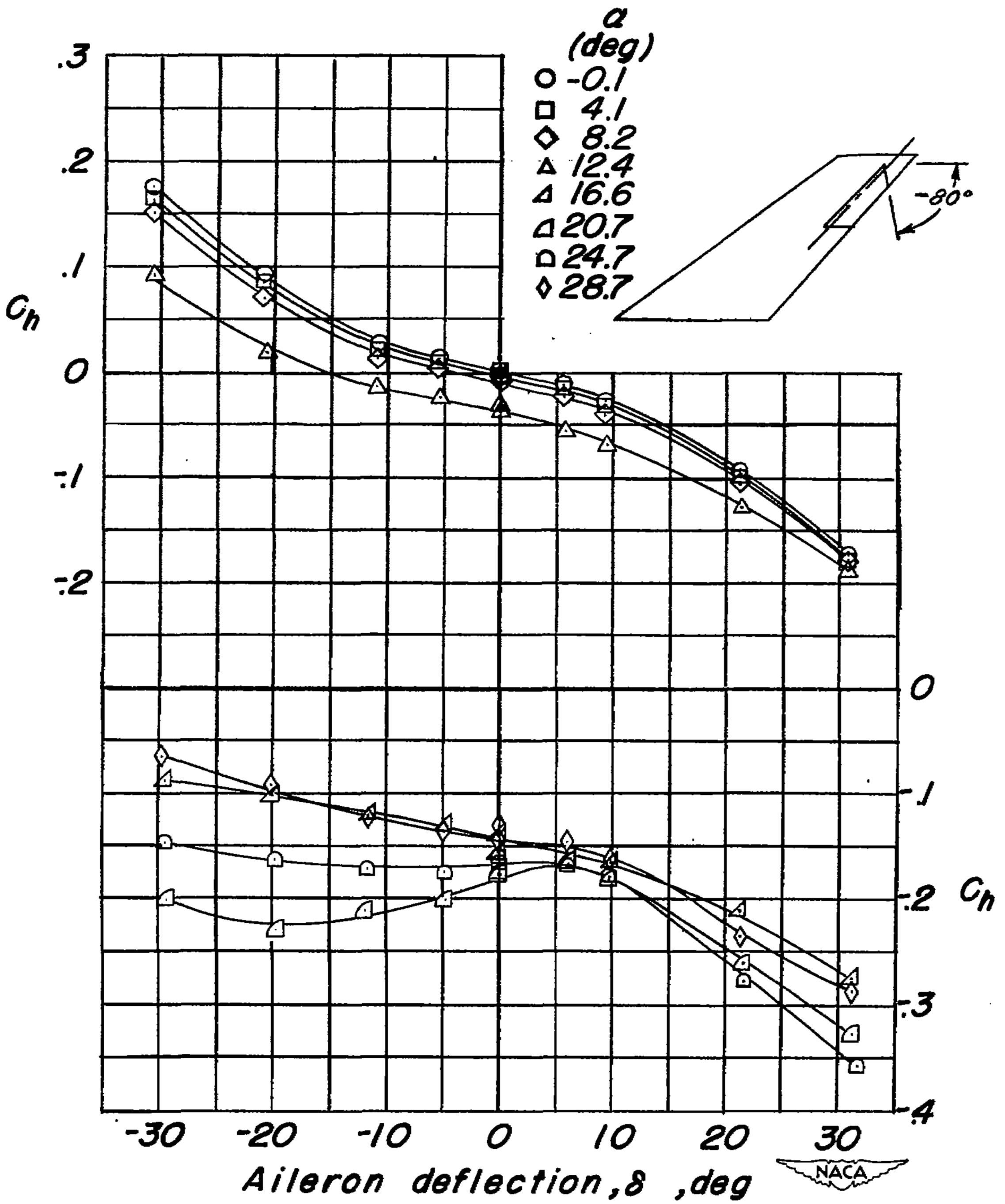
(b) Concluded.

Figure 7.- Continued.



(c) Outboard aileron tip at an angle of -80°.

Figure 7.- Continued.



(c) Concluded.

Figure 7.- Concluded.

[redacted]

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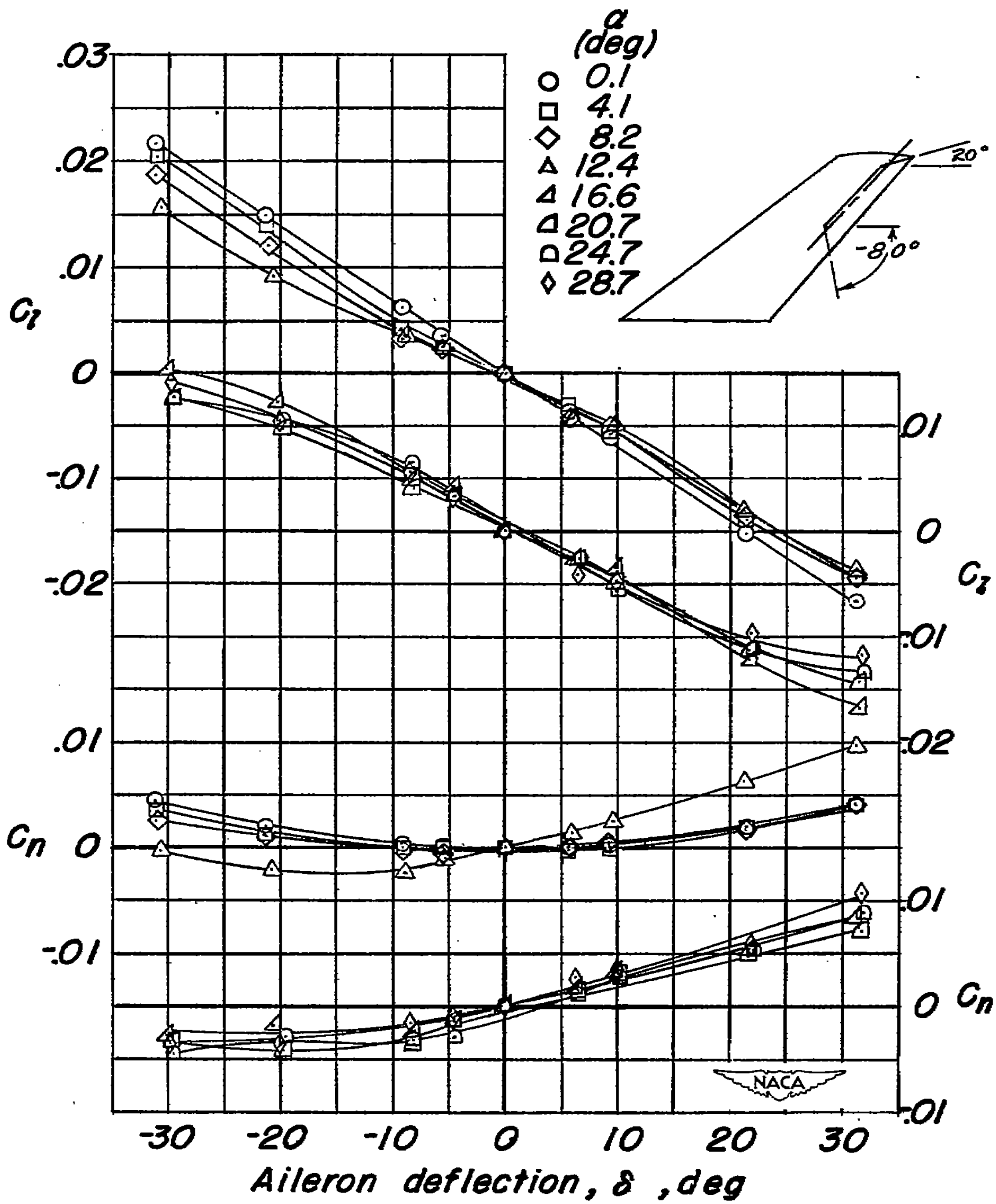

Figure 8.- Variation of lateral-control and hinge-moment characteristics with aileron deflection on the 51.3° sweptback wing with the inboard aileron tip at an angle of -80°, and the outboard tip at an angle of 20° with respect to the plane of symmetry.

[redacted]

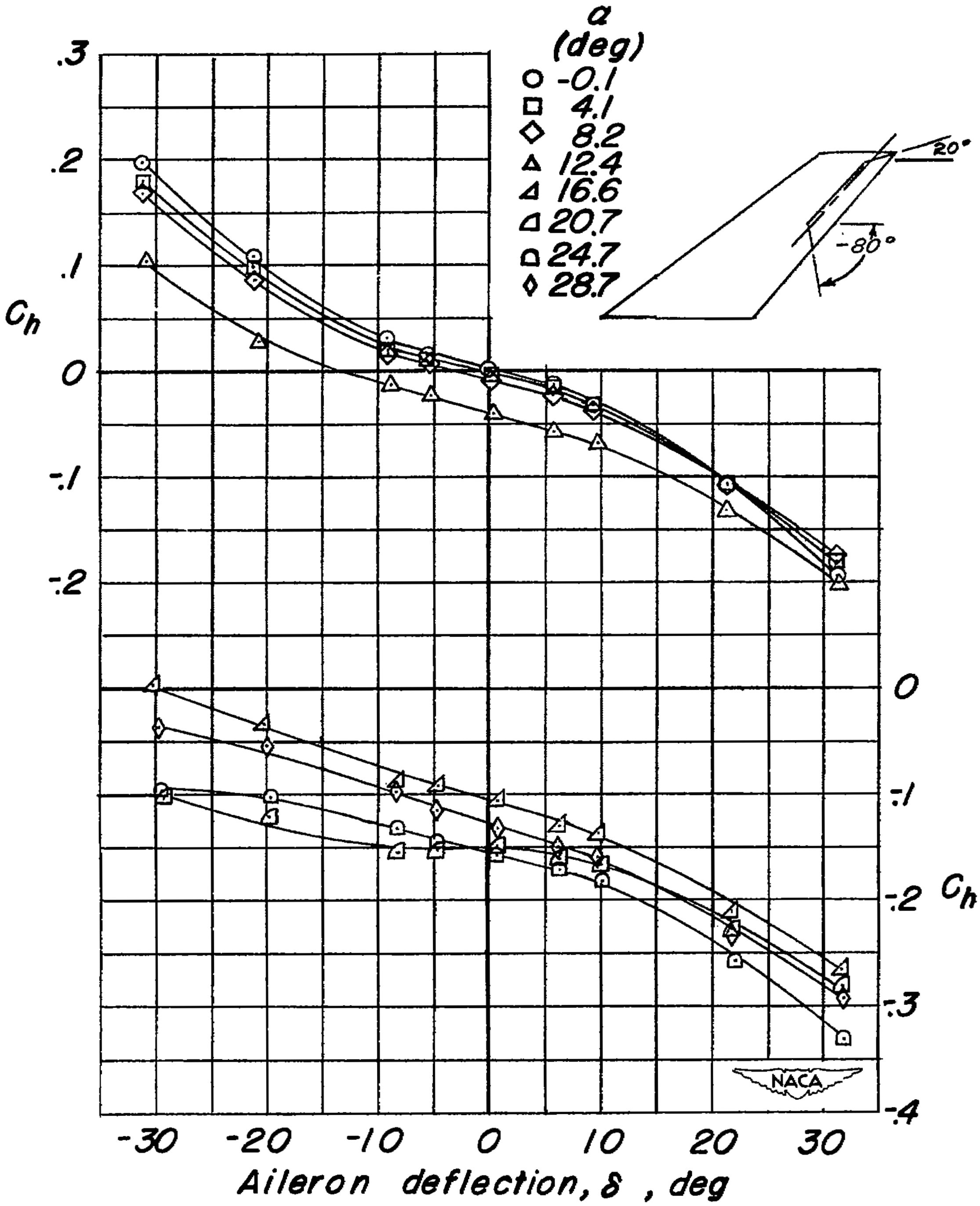

Figure 8.- Concluded.

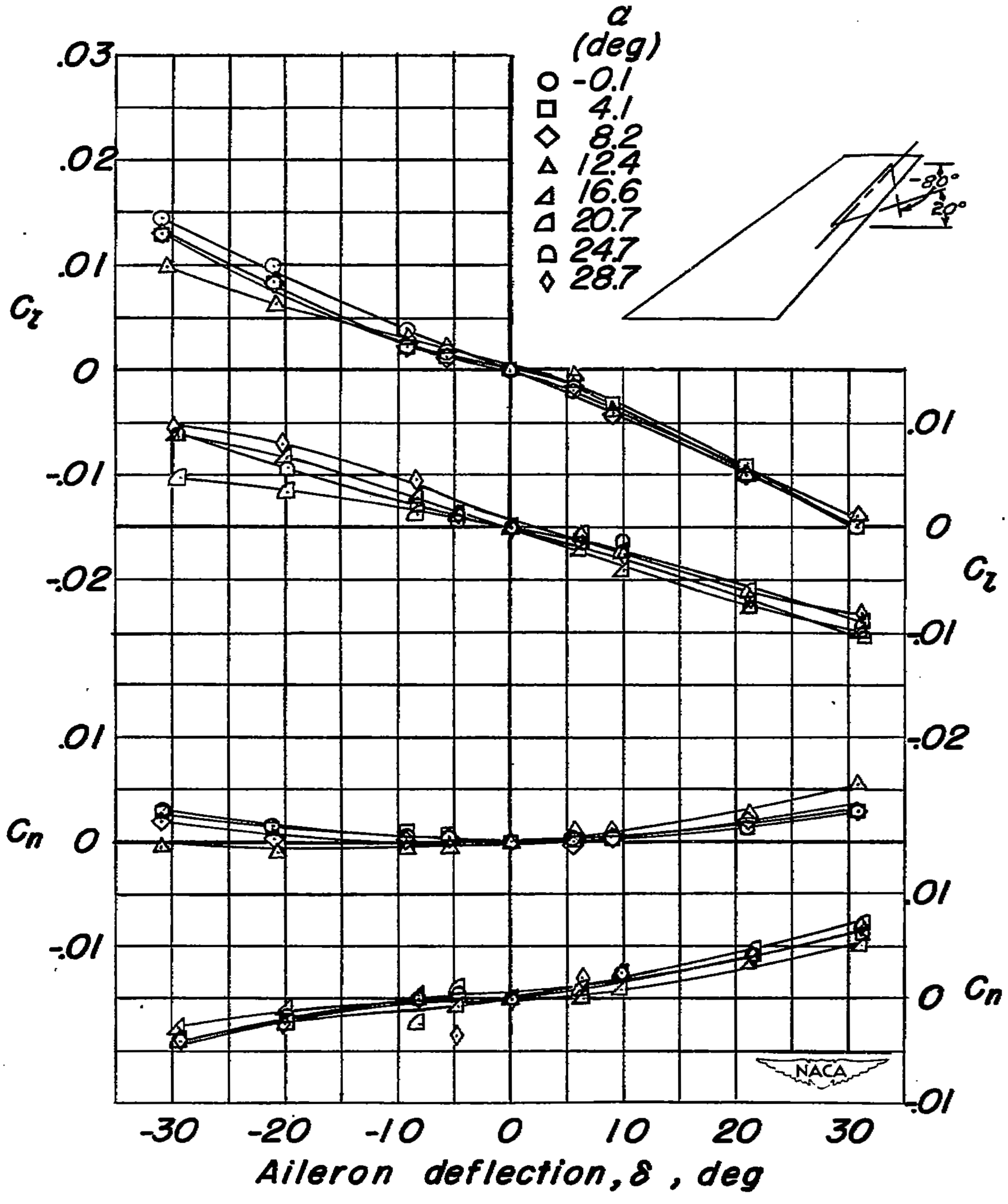

Figure 9.- Variation of lateral-control and hinge-moment characteristics with aileron deflection on the 51.3° sweptback wing with the inboard aileron tip at an angle of 20°, and the outboard tip at an angle of -80° with respect to the plane of symmetry.

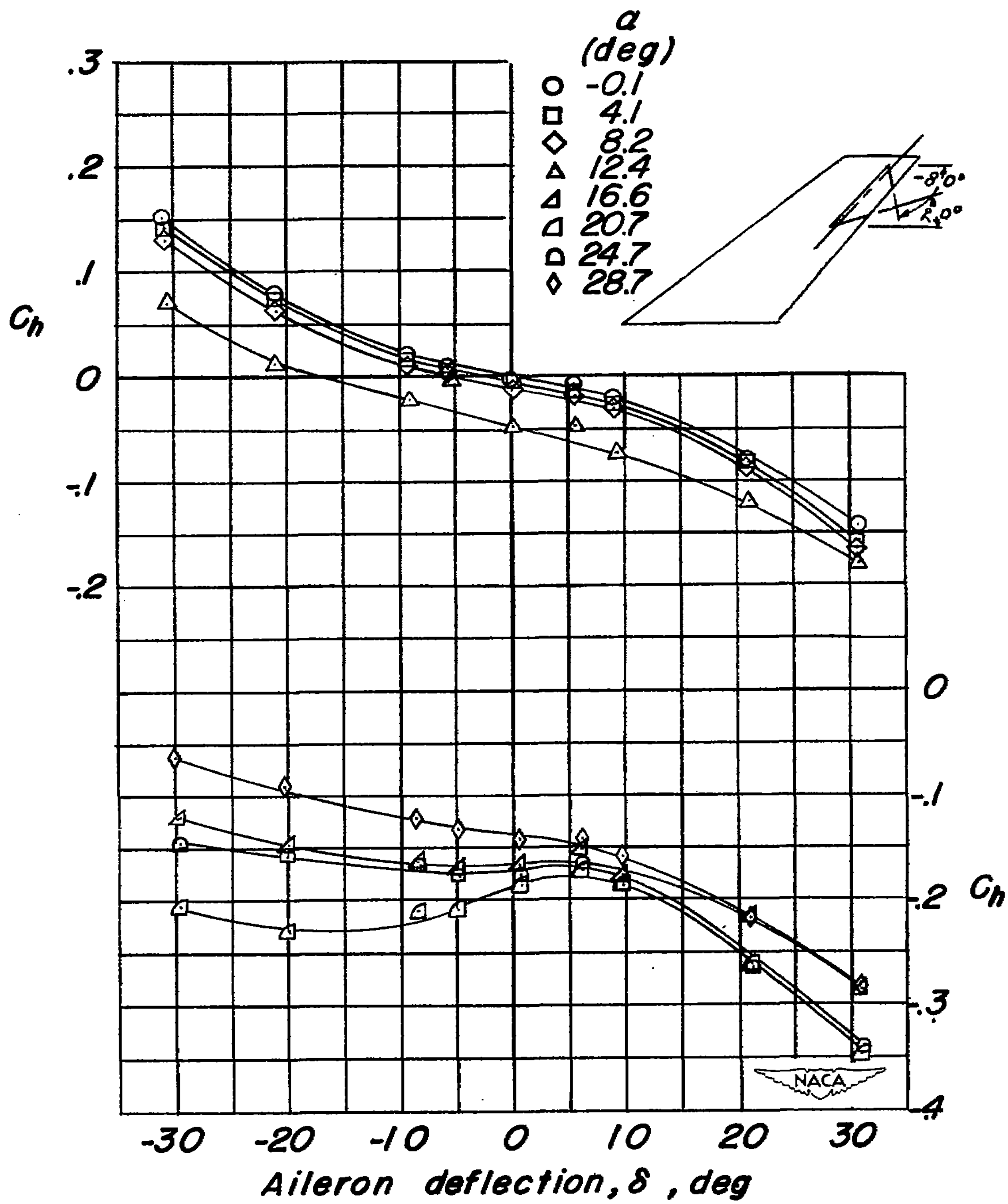

Figure 9.- Concluded.

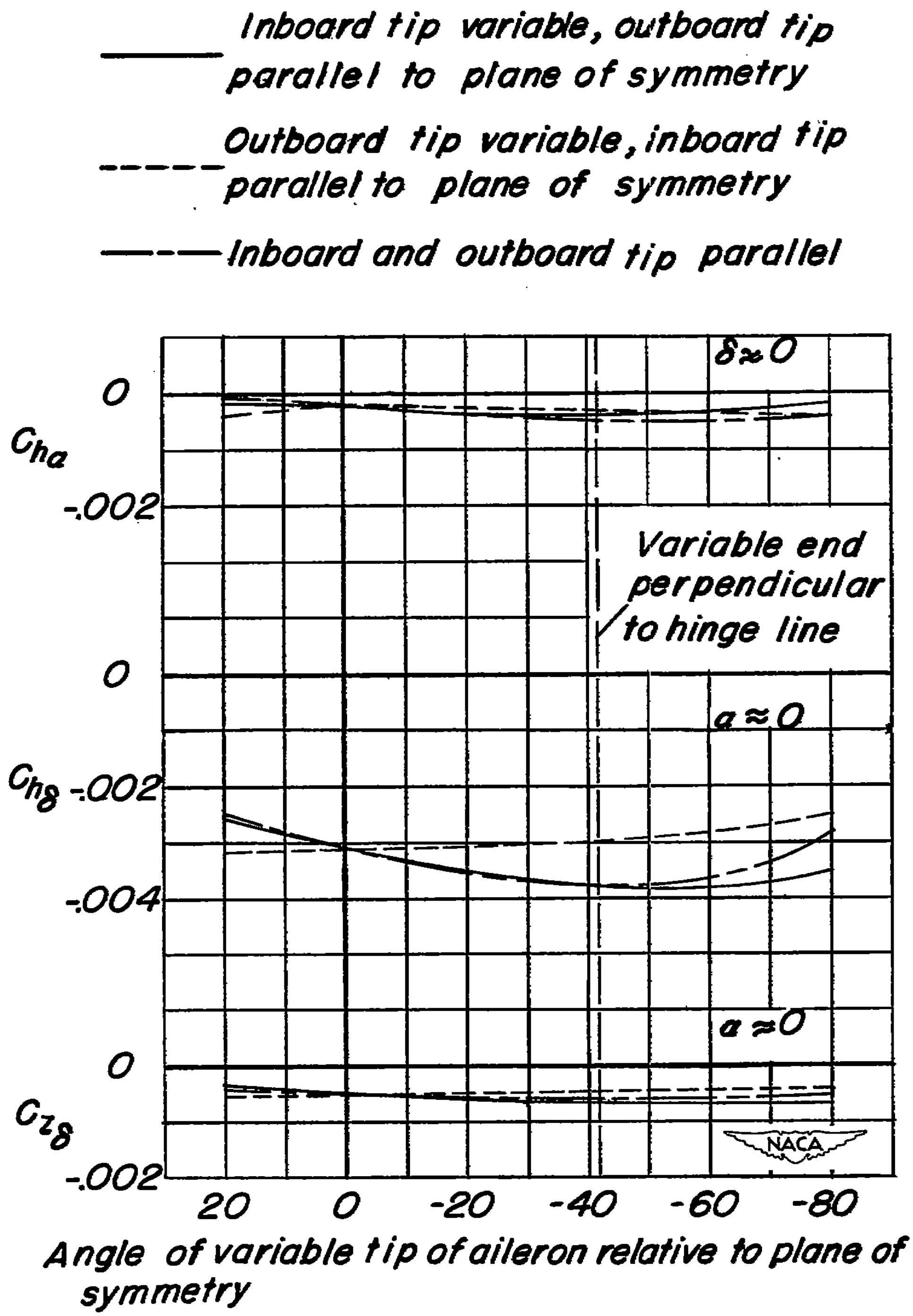

Figure 10.- Variation of the aileron lateral-control parameters C_{h_α}, C_{h_δ}, and C_{l_δ} with the angle of the aileron tips for several variations of aileron plan forms.

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